Metropolitan District Commission
Division of Watershed Management

Water Quality Report: 2002
Quabbin Reservoir Watershed
Ware River Watershed

June 2003

ABSTRACT

The Metropolitan District Commission Division of Watershed Management was established by Chapter 372 of the Acts of 1984. The Division was created to manage and maintain a system of watersheds and reservoirs and provide pure water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to approximately 2.5 million people in forty-six communities.

Water quality sampling and watershed monitoring make up an important part of the overall mission of the Division. These activities are carried out by Environmental Quality Section staff at Wachusett Reservoir in West Boylston and at Quabbin Reservoir in Belchertown. This report is a summary of 2002 water quality data from the Quabbin Reservoir and the Ware River watershed. A report summarizing 2002 water quality data from the Wachusett Reservoir watersheds is also available from the Division.

Acknowledgements:

This report was prepared by the Quabbin Environmental Quality Section of the Metropolitan District Commission's, Division of Watershed Management. Scott A. Campbell, Environmental Engineer II was the principal author. The following MDC staff provided analytical and field support, and provided comments on this report:

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Dave Worden, MDC Limnologist collected reservoir samples for nutrient analyses, and collected and analyzed samples of phytoplankton. Dave Worden also provided language used in this report for the interpretation of 2002 nutrient results. The Quabbin Civil Engineering Section provided meteorological and reservoir yield data reproduced in this report. The U.S. Geological Survey through a cooperative agreement established with the MDC provided tributary flow data appended to this report.

Environmental Quality Section staff would like to acknowledge the loss to retirement of one of its co-workers, David Chandler, Environmental Analyst I. Dave worked in the Quabbin Laboratory from 1983 to 2002. Dave has served as the primary laboratory chemist since 1983. Among Dave's accomplishments are his contributions to the Phase I Acid Rain Monitoring Program and the extensive paper mapping of the water quality monitoring program prior to the widespread use of the Massachusetts Geographic Information System. However, Dave's most significant contribution to the laboratory was bringing laboratory recordkeeping into the digital age, having established and maintained the computer database that to this day stores fifteen years of records. Dave's contribution and presence about the lab will be missed.

MDC/DWM thanks the staff and management of the MWRA Deer Island Laboratory for preparing and delivering sample bottles and performing all nutrient analyses during the year.

All maps were produced by MDC/DWM GIS analyst Phillip Lamothe, using the most recent MDC and MassGIS data.

The photographs on the cover of this report are of the Quabbin Reservoir Western Arm and of Cadwell Creek in Belchertown, and were taken from the MDC/DWM Visitor Center archive.

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EXECUTIVE SUMMARY

The Metropolitan District Commission, Division of Watershed Management (MDC-DWM) is legislatively mandated to manage and maintain a system of watersheds and reservoirs in order that pure water can be provided to the Massachusetts Water Resources Authority (MWRA). Specifically, Chapter 372 of the Acts of 1984 established the MWRA as in independent agency whose chief responsibility was the delivery and distribution of drinking water to approximately 2.5 million people across Massachusetts. The primary function of the MDC-DWM in this partnership is to provide active watershed management, the first line of defense against drinking water contamination.

A major effort of the Division's watershed management program is its water quality monitoring program. The MDC Quabbin Section currently operates a state-certified water quality testing laboratory staffed by a diverse group of professionals, collectively referred to as the Environmental Quality Section (EQS). The EQS staff is trained in a variety of areas including microbiology, public health and the environmental sciences. The EQS is responsible for gathering and interpreting data on water samples collected from Quabbin Reservoir source waters. In 2002, the MDC Quabbin laboratory processed 2,975 individual tributary and reservoir samples for in-house analysis; 2,073 samples for microbiological analysis and 902 samples for chemical analysis. Results from the extensive water quality program are used to assess compliance with Massachusetts drinking water standards for source waters and to monitor the ecological health of the system. Results also provide general direction and guidance for DWM management programs and research directives.

The Quabbin Reservoir is currently one of only a handful of large surface water supplies that maintains a filtration waiver from the federally mandated Surface Water Treatment Rule (SWTR). The SWTR in effect requires filtration by every surface water supplier unless strict source water quality criteria and watershed protection controls can be met. The purpose of the SWTR is to ensure that public water supply systems using surface waters protect against waterborne diseases that may result from exposure to such microorganisms as *Giardia lamblia* and viruses. Source water quality compliance relies on a surrogate parameter, turbidity, and an indicator organism, fecal coliform bacteria, to provide a relative measure of the sanitary quality of the water.

SWTR Source Quality Criteria

- Coliform Limits: Six-month, running compliance period in which fecal coliform ≤20/100 mL in 90% of samples.
- Turbidity Limits: Before disinfection, turbidity not to exceed 5 NTU* based on sampling at 4-hour intervals. *MA DEP has set a performance standard of 1 NTU.

The Quabbin Reservoir has fully met the SWTR Source Quality criteria since June 1991, thanks in large part to a successful Gull Control Program. Source water fecal coliform bacteria levels are monitored daily by the MDC at Site 201, located on the Chicopee Valley Aqueduct service line prior to disinfection. Historic data from Site 201 over the 1990-1999 period show that both fecal coliform bacteria and turbidity levels are low averaging 1 colony forming unit (CFU) per 100 milliliters (mL) and 0.3 NTU respectively. 2002 levels were nearly unchanged as fecal coliform bacteria levels averaged less than one colony forming unit per 100 mL and turbidity levels averaged 0.4 NTU. Fecal coliform bacteria was absent in 84% of the 435 samples collected. One sample exceeded the 20

CFU/100mL standard with a result of 21 CFU / 100 mL on December 12. The exceedance was the first since December 1994 and came during a time when gull harassment efforts were being carried out infrequently (1 to 3 times per week) due to budget constraints. The result was a higher number of untrained gulls being left alone to presumably loaf in the vicinity of the CVA intake. The next highest fecal coliform level was 7 CFU per 100mL detected on December 17, measured at a time when full-time harassment measures had been re-instated.

The Massachusetts Department of Environmental Protection standard for source water turbidity for unfiltered water supply systems is a maximum of 1.0 NTU; the EPA standard is a maximum of 5.0 NTU. Results from MWRA's online turbidimeter exceeded the DEP standard on December 25th and 26th due to high winds caused by a major Nor'Easter Storm. The maximum source water turbidity reached was 1.96 NTU and the Ware Disinfection facility was shutdown for approximately 7 hours to allow for winds to diminish. Quabbin Reservoir's "Below normal" water level status is being blamed for the problem as wave action against the exposed sandy shore can stir-up and suspend turbidity, in particular along the southern shore of the Winsor Basin. In weekly assessment monitoring performed by the MDC at Site 201 (Winsor Power Station), turbidity levels were measured at their highest at 0.6 NTU on two occasions, June 10 and August 19. Weekly monitoring results were observed to remain characteristically stable throughout the year and averaged 0.4 NTU.

Under the requirements of the Surface Water Treatment Rule extensive testing at several locations on the reservoir and aqueducts is also mandated. Only the testing operations performed on the Chicopee Valley Aqueduct, community service line and coordinated with the MDC Drinking Water Laboratory are discussed in this report. In that arrangement, the MWRA has prescribed a schedule of quality assurance sampling to include a daily sample from the Ludlow Monitoring Station and Winsor Power Station (SS 201), and a sample "as often as possible" (generally 5 times per week) from the Nash Hill tank. Each sample is analyzed for total coliform bacteria and chlorine residual (if treated water). In 2002, the MDC laboratory analyzed 610 "finished water" samples for presumptive total coliform bacteria. On one occasion, the Nash Hill tank sample tested and was confirmed positive for total coliform bacteria. All other CVA samples, including repeat samples following the incident, were absent of total coliform bacteria. Results from daily total coliform tests performed at Site 201, Winsor Power Station prior to disinfection were similar to recent years because levels became elevated between the months of August thru October. Total coliform concentrations during this period averaged 109 CFU / 100 mL and high background levels necessitated 5 mL dilutions due to excessive overcrowding and spreading growths. However, as a whole the 2002 levels were lower than previous years and the duration of the apparent bloom was shortened. To date, investigations into reservoir levels, precipitation patterns, and reservoir yield have not produced any clear statistical explanation for the trends in total coliform levels (Long and Lee, 2002).

Environmental Quality staff continued to monitor site-specific water quality impacts related to development pressures, wildlife populations and construction activities. Special investigatory samples were collected on the Middle Branch Swift River in New Salem, Cobb Brook in Shutesbury, and Purgee Brook in Pelham, Massachusetts. The 2002 pathogen monitoring program continued to focus on collecting baseline data on the occurrence of *Giardia* and *Cryptosporidium*. Water entering the Chicopee Valley Aqueduct prior to disinfection was sampled every two weeks from the Winsor Power Station building tap (Site 201). Of the 24 samples collected and analyzed for *Giardia* and *Cryptosporidium*, none of the results were above detection limits that ranged from 0.26 to 1.32 cysts per 100 liters (source: Erie County Laboratory, New York).

In 2002, the MDC continued a collaborative effort with the University of Massachusetts, Environmental Engineering Program on an American Water Works Association Research Federation (AWWARF) study that looks to quantify storm water generated, microbiological loadings from various land uses. Two monitoring stations have been selected inside of the Quabbin Reservoir watershed because of their proximity to wildlife populations and location inside a virtually undeveloped sub-watershed. Two stations, an upstream and downstream location bordering a cow pasture within the Ware River watershed were also added in the late summer. The MDC Quabbin laboratory is contributing by providing laboratory support and analysis of microbiological samples. The MWRA Central laboratory has also been providing support for the analysis of nutrients. In 2002, MDC staff processed eighty-three samples and performed analysis on each for total and fecal coliform bacteria. Heterotrophic plate count analysis was also performed on 49 storm water samples collected from three storm events. The MDC will continue to analyze background and storm-event microbiological loadings in 2003.

2002 will most likely be remembered for the warmer and drier than normal conditions that persisted throughout the first three quarters of the year. The climatological winter (December thru February) was officially the warmest on record with an average temperature 7.1°F above normal and more strikingly, 73 of 90 days (81%) had above normal temperatures (source: National Weather Service). The entire state began the year under a drought advisory issued by the Massachusetts Drought Management Task Force and by late August cumulative precipitation totals were 5 ½ inches below normal for the year. Water storage effects from the extended drought conditions that ended the year in 2001 were first observed in February 2002 as the Quabbin Reservoir entered into the "Below Normal" operating status for the first time since 1989. Quabbin Reservoir began the month of February 2002 at elevation 520.76 or 83% capacity. A temporary reprieve in falling reservoir levels was afforded by much needed precipitation in May and June. However, following the peak elevation of 522.84 (86.8% full) achieved on June 15, reservoir levels began another steady decline that lasted until the minimum elevation of 516.48 (75.5% full) was reached on November 11. Unlike most eastern Massachusetts communities who were forced to institute watering bans, the MWRA service communities were able to continue to deliver water without any disruption or restrictions placed on the delivery of the water due to the reservoir's large storage capacity (412 billion gallons). Although Quabbin Reservoir ended the year under a "Below Normal" operating status, signs of an official drought recovery were apparent when on December 18, 2002, the Massachusetts Drought Management Task Force had recommended that the "Drought Advisory Level" be eliminated for all of the state with the exception of Cape Cod and the islands.

As alluded to earlier, the drought has been indirectly linked to water quality effects observed in the reservoir. Specifically, high turbidity events linked to the greater degree of exposed, erodable shore lines at the lower elevation stage. Moreover, results from reservoir quarterly nutrient sampling in 2002 generally registered at the low end of historical ranges. In particular, silica and UV absorbance were measured at concentrations and intensities below the minimum values observed to date. The lowest values of these two parameters were generally observed in October and likely reflect a longer hydraulic residence time and a paucity of runoff resulting from the drought (Worden, 2002). The MDC/MWRA reservoir nutrient monitoring program that was begun in 1998 is expected to continue into 2003 with no major changes in sampling locations or parameters.

The Quabbin Reservoir Water Quality Monitoring Program, briefly highlighted above, is a large-scale effort that produces a wealth of valuable information utilized for watershed protection and compliance purposes. The purpose of this report is to present Calendar Year (CY) 2002 water quality results from source water monitoring performed on Quabbin Reservoir and its tributaries, including those within the Ware River watershed. Three major sections are presented in this report. Section 1 is presents a general description of the system and its hydrological characteristics and draws largely on raw data collected and maintained by the Quabbin Civil Engineering Section and the U.S. Geological Survey. Data is presented on precipitation, reservoir yield data and stream flows. Section 2 outlines the current water quality monitoring program with descriptions of sampling locations, frequencies and parameters of study. Physical and chemical data for principal Quabbin Reservoir inlets and outlets is presented in Table 4. Summary data for the Ware River Intake at Shaft 8 is presented in Table 5. Similar data is presented for combined Quabbin Reservoir and Ware River tributaries in Tables 9 and 10. Information on sample site locations is presented in Tables 6 and 7 and Figures 8 and 9. Section 3 is devoted to a series of specialized studies and investigations in which the EQ Section was an active participant. The specialized investigations cover a variety of issues and often last only for a short-term. Figures and tables presented in this report are meant simply to organize the wealth of water quality data generated annually into a meaningful format based on the source supply and its contributing tributaries. Appendix A contains tables of data collected at each individual site and reports each site's yearly minimum, maximum, median and average values.

1.0 CHARACTERIZATION OF THE QUABBIN RESERVOIR WATERSHED SYSTEM

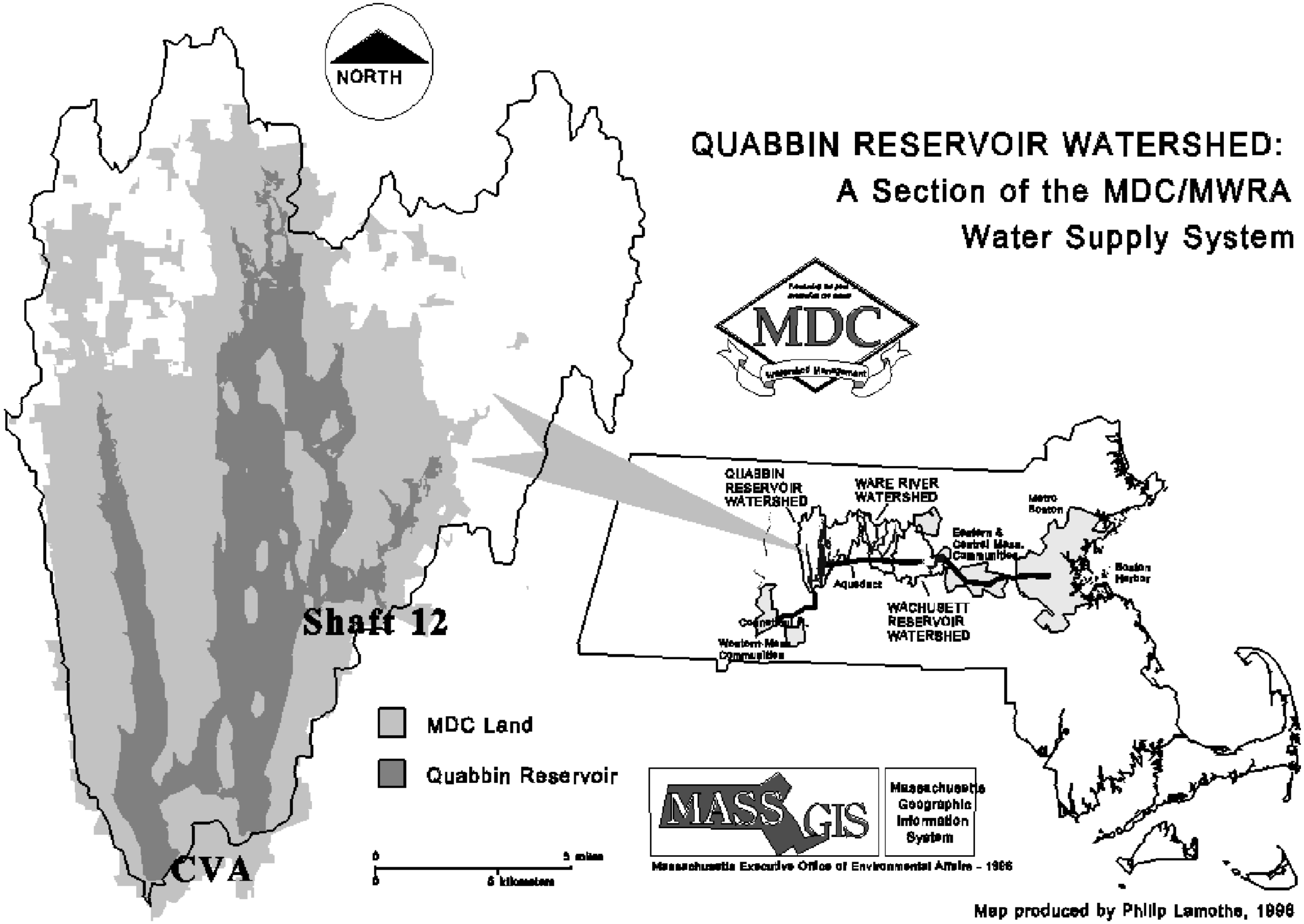
Figure 1 shows the Quabbin Reservoir, Ware River and Wachusett Reservoir watershed system that supplies drinking water to Boston and 45 other member communities that make up the MWRA service territory. The largest of the three interconnected sources is Quabbin Reservoir, a 412 billion gallon impoundment of the Swift River located in Central Massachusetts. Quabbin Reservoir water transfers to Wachusett Reservoir via the Quabbin Aqueduct Intake at Shaft 12 typically account for more than half of MWRA's system supply. Quabbin Reservoir also supplies a much smaller amount of water directly to three western Massachusetts communities via the Chicopee Valley Aqueduct (CVA). Water is delivered to the service communities via two, gravity fed aqueduct systems whose intake structures are labeled in Figure 1. The Quabbin Aqueduct intake at Shaft 12 is located along Quabbin Reservoir's eastern shoreline in Hardwick, Massachusetts. The CVA intake lies at the base of Winsor Dam in Belchertown, Massachusetts. MDC has maintained a SWTR, filtration waiver status for its CVA supply since 1992. A filtration waiver for the Wachusett Reservoir also exists. The focus of this report is the Quabbin Reservoir watershed and supplemental supplies from Ware River diversions. Land use characteristics of the contributing watersheds are summarized below.

Quabbin Reservoir watershed is about 19 miles long, 13 miles wide, and contains roughly 120,000 acres. More than 90% of watershed lands are forested and the Metropolitan District Commission owns and controls 53,000 acres (55%) for water supply protection. The majority of non-MDC owned land is maintained as private forest. Developed lands in the watershed can be characterized as sparsely populated and having limited agricultural sites.

Aerial Photo: Western Arm of Quabbin Reservoir.

The Ware River watershed is about 11 miles long, 7 miles wide, and contains roughly 62,000 acres. Nearly 75% of the watershed is forested and the Metropolitan District Commission owns and controls 22,000 acres (35%) for water supply protection. The vast majority of private lands are maintained as forests and developed lands consist primarily of low density residential and agricultural sites. Waters from Ware River are diverted into the Quabbin Aqueduct at Shaft 8 in Barre and directed west towards Quabbin via gravity flow. Diversions are limited to periods when Ware River flows exceed 85 MGD and require DEP approval unless conducted during the allowable diversion period from October 15 to June 15.

No wastewater treatment plant discharges are currently permitted in tributaries to either of the three water supply watersheds. Industrial and commercial land uses throughout the Quabbin and Ware River watersheds are limited and make-up less than ½ percent of the total land area.


QUABBIN RESERVOIR WATERSHED:
A Section of the MDC/MWRA
Water Supply System
NORTH
MDC
Shaft 12
CVA
MDC Land
Quabbin Reservoir
0 5 miles
0 5 kilometers
QUABBIN RESERVOIR WATERSHED
WARE RIVER WATERSHED
Metro Boston
Eastern & Central Mass. Communities
Boston Harbor
Aqueduct
WACHUSETT RESERVOIR WATERSHED
Connecticut R.
Western Mass. Communities
MASS GIS
Massachusetts Geographic Information System
Massachusetts Executive Office of Environmental Affairs - 1996
Map produced by Philip Lamothe, 1996

PRECIPITATION

Since 1939, the MDC and its predecessors have maintained a weather monitoring station at the MDC Administration Complex in Belchertown, Massachusetts. Presently, daily (Monday thru Friday) temperature, rainfall, and snowfall data is being collected by the MDC Civil Engineering Section. Historically, annual precipitation has averaged just slightly below forty-six inches and average monthly precipitation that is distributed equally throughout the year ranges between 2.95 and 4.37 inches (months of February and August respectively). The bar chart on the following page summarizes monthly precipitation data from 2002 and presents historical data from the 1939-2002 reference period.

Precipitation for Calendar Year 2002 was generally in the normal range with only a 1.91 inch deficit below the forty-six year average of 45.80 inches. The 2002 precipitation total of 43.89 inches represents a 10% increase from the 2001 total. However, the year will be remembered for the mild drought conditions that were present statewide and persisted throughout the year. The Massachusetts Drought Management Task Force issued a statewide drought advisory level beginning in December 2001. The advisory level was changed to a watch status issued in March 2002 because of drier than normal conditions at the start of the year. Sufficient rains in May changed the status to an advisory level where it remained until December when the drought advisory was rescinded. Months with drier than normal precipitation totals with deficits of one inch or more included January, April and August. Two months, February and July, were notably dry with totals ranking among the lowest 20 percent of records kept since 1939. Monthly precipitation totals were within a normal range of conditions for the months of March, May, June and October. Only three months, September, November and December were wetter than normal with surpluses of one inch or more. The wetter than normal months that ended the year erased a precipitation deficit that peaked in August at 5.61 inches. Throughout the year ten storm events equaled or exceeded one inch of precipitation in a 24 hour period. December and November were the only months within which multiple (2) one-inch plus storm events occurred. There was one significant storm event that occurred on May 12 and 13, dumping 2.28 inches of rain over a 48 hour period.

The winter season (November 2001 through April 2002) snowfall total of 27.5 inches was significantly lower than the seasonal average of 48.21 inches. The lack of snow reflects both drier than normal conditions and the record setting warm winter of 2001-2002. A significant wintertime snowpack was never truly obtained as peak snow depths in the range of 5-10 inches were reported by the U.S. Army Corps on January 22, 2002. The US Army Corps Snow Depth chart (right) exhibits the absence of springtime snow cover throughout Southern New England. Regional measurements were discontinued after March 18 due to the lack of snow.

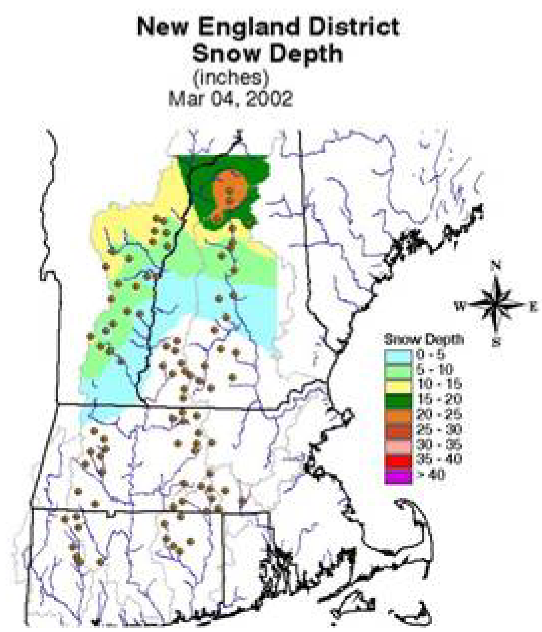
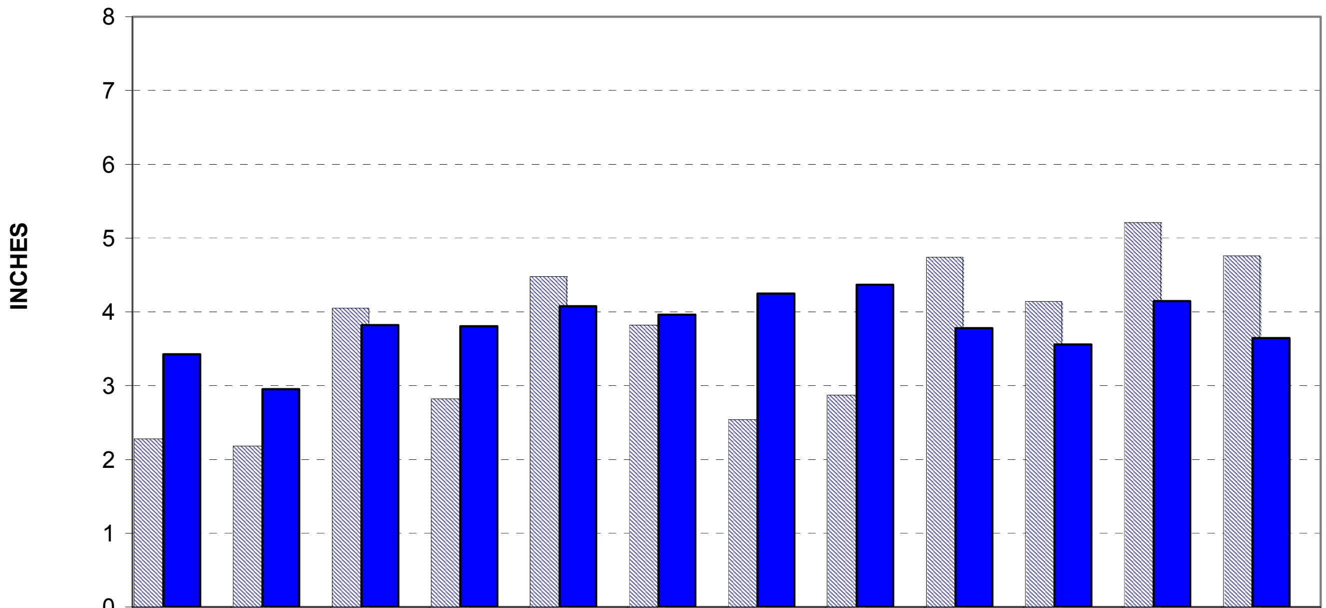


Figure 2

2002 MONTHLY PRECIPITATION
VS. 64 YEAR AVERAGE
(1939-2002) BELCHERTOWN, MA



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Precipitation (in.)	2.28	2.18	4.05	2.82	4.48	3.82	2.54	2.87	4.74	4.14	5.21	4.76
Departure from Norm (in.)	-1.14	-0.77	0.23	-0.98	0.40	-0.14	-1.71	-1.50	0.96	0.58	1.06	1.11
Cumm. Departure (in.)	-1.14	-1.91	-1.68	-2.67	-2.27	-2.41	-4.12	-5.61	-4.65	-4.07	-3.01	-1.89
Number of Storms >1.0 in.	0	0	0	0	1	1	1	1	1	1	2	2
64 Year Average Precip. (in.)	3.42	2.95	3.82	3.80	4.08	3.96	4.25	4.37	3.78	3.56	4.15	3.65
64 Year Minimum	0.70	0.48	0.55	0.87	0.90	1.10	0.84	0.89	0.86	0.56	0.93	0.76
64 Year Maximum	10.21	7.03	7.58	9.11	13.09	9.62	9.45	22.96	11.55	11.08	7.32	8.19
20 Percent Exceedance	4.76	3.84	5.08	5.25	5.41	5.21	5.67	6.01	6.22	5.18	5.69	5.11
80 Percent Exceedance	1.97	2.10	2.49	2.18	2.71	2.47	2.65	2.01	1.89	2.03	2.73	2.27
Snow (in.)	11.5	2.0	9.0								8.0	20.0

Source: MDC Civil Engineering Yield Data, 1939-2002

STREAM FLOWS

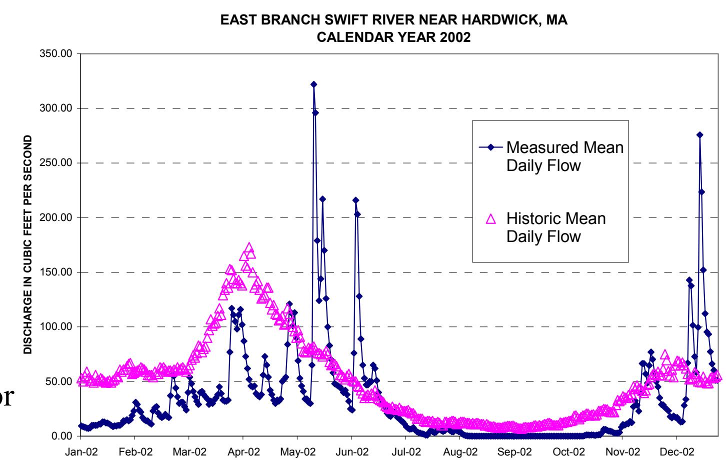
Through a cooperative agreement with the United States Geological Survey (USGS), five stream gages are actively being monitored inside the Quabbin Reservoir and Ware River watersheds. Stations include sites on the Ware River in Barre (at intake), Ware River at Barre Falls, East Branch Swift River in Hardwick, West Branch Swift River in Shutesbury, and the Swift River below Winsor Dam. Daily mean discharge values were provided by the U.S. Geological Survey, Water Resources Division. Plots of stream hydrographs and tables of daily mean values are included in the appendix of this report.

2002 Annual Mean Daily Discharges

Ware River at Intake Works: 96.5 cfs
East Branch Swift River: 33.7 cfs
West Branch Swift River: 12.2 cfs
Swift River at Ware: 50.5 cfs

Runoff for 2002 was generally below normal as surface water conditions were at no time characterized as above normal (exceeding the 75 percentile mark of historical records). Lingering effects from the mild drought conditions that began the year could be seen as new record minimum monthly mean daily stream flows were established on the West Branch Swift River (January, February, March and August), East Branch Swift River (March) and the Ware River at Barre Falls (July, August and September). Mean monthly flows in the Ware River measured downstream of the intake works were only just slightly above record minimums for the months of March, August and September. Only during the months of April, May, June, November and December were stream flow conditions at or near normal conditions.

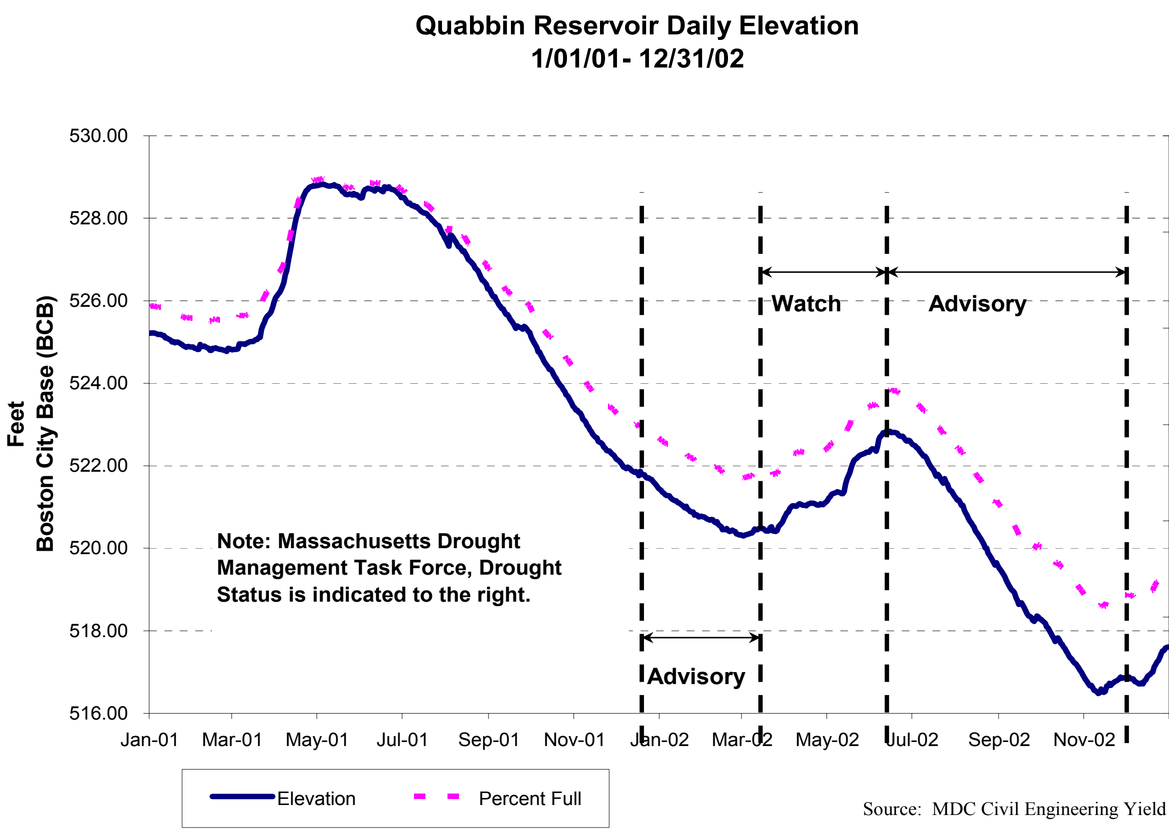
On May 14 both the East Branch Swift River and West Branch Swift River experienced peak mean daily flows of 322 cfs and 125.5 cfs respectively. Mean daily flows in the Ware River peaked at 591 cfs on March 29 at Shaft 8 and at 336 cfs on May 16 at Barre Falls Dam . Flow in the Swift River near Ware is a function of controlled releases fromWinsor Dam and spillway discharges. The peak mean daily flow was measured at 119.3 cfs on October 12. Minimum mean daily flow on the Ware River at Shaft 8 was measured at 5.4 cfs on August 27. Minimum mean daily flow on the West Branch Swift River was measured at 0.6 cfs on September 13. The East Branch Swift River had no measurable flow to the reservoir (via horseshoe dam) for a period of 60 days beginning on August 14 and ending October 12. The longest span of no measurable flow in the Ware River at Barre Falls Dam was three days and this occurred on three occasions in July, September and October.



Hydrograph: East Branch Swift River, Hardwick

RESERVOIR CONDITIONS

Quabbin Reservoir storage capacity began 2002 at 84.3% and ended at 77.50% capacity. The reservoir had dipped to below normal operating levels and reflects the fact that the reservoir never completely filled during the spring as is normal. The maximum reservoir elevation reached 522.84 on June 13 and 15. The minimum elevation of 516.48 (75.5% capacity) was reached on November 11. Due to the Quabbin Reservoir's large storage capacity at 412 billion gallons, the MWRA was able to provide an unrestricted supply of water despite operating under a "Below normal" status beginning in February 2002. The reservoir delivered on average 8.7 million gallons per day (MGD) to the Chicopee Valley Aqueduct service area over the course of 365 days. During the 269 days that water was released to Wachusett Reservoir, flow entering the Quabbin Aqueduct averaged 223.7 MGD. To supplement Quabbin Reservoir levels a total of 5,246.2 million gallons of water was diverted from Ware River. Ware River diversions occurred over a course of 71 days and flows averaged 73.89 MGD.



Source: MDC Civil Engineering Yield Data, 2001-02

In 2002, the deep reservoir basins at Shaft 12 and the Winsor Dam never became ice-covered due to record setting winter warmth. This past winter established a new high average temperature mark of 33.1°F, a departure of +7.1 °F above normal (source: National Weather Service). Average daily temperatures were above normal on 73 of 90 (81%) days and 10°F was the lowest the thermometer dipped. Table 1 on the following page presents general statistics on the reservoir and contributing watershed area and presents a comparison of reservoir conditions over the past three years.

TABLE 1
QUABBIN RESERVOIR FACTS AND FIGURES

FACTS ABOUT THE RESERVOIR		FACTS ABOUT THE WATERSHED	
Capacity	412 Billion Gals	**Watershed Area**	120,000 acres
Surface Area	24,000 acres	**Land Area**	96,000 acres
Length of Shore	118 miles	**MDC Owned Land**	53,000 acres
Maximum Depth	150 feet	**% MDC Owned**	55%[1]
Mean Depth	45 feet	**Forested Lands**	83,235 acres
Surface Elevation	530 feet	**Wetlands**	5,289 acres
Year Construction Completed	1939	**Avg. Reservoir Gain From 1" of Precipitation**	1.6 Billion Gallons

Calendar Year:	2002	2001	2000
Maximum Reservoir Elevation (ft)	522.84 on June 13 & 15	528.53 on May 5	528.62 on June 28
Minimum Reservoir Elevation (ft)	516.48 on May 5	521.46 on December 31	522.40 on February 11 & 13
Total Diversions to Wachusett Reservoir	60,108.8 MG (269 days: 224 MGD)	62,447.8 MG (294 days: 212.4 MGD)	42,708.7 MG (233 days: 183.3 MGD)
Total Diversions to CVA	3,161.2 MG (365 days: 8.7 MGD)	3,296.7 MG (365 days: 9.0 MGD)	2,816.4 MG (365 days: 7.69 MGD)
Ware River Transfers	5,246.2 MG (71 days: 73.9 MGD)	4,122.7 MG (11 days: 4/12-4/22)	603.8 MG (4 days: 3/21-3/24 & 3/27-3/28)
Spillway Discharges	NONE	2,537.3 MG (93 days: 4/16-7/20)	474.6 MG (44 days: 6/11-7/19 & 8/11-8/17)
Total Diversions to Swift River	12,467.9 MG (34.2 MGD)	18,334.2 MG (50.2 MGD)	9,324 MG (25.5 MGD)
Reservoir Ice Cover	Full reservoir ice cover not obtained.	≈100% cover: January 23 through March 25 (61 days).	100% cover: January 24 through March 12 (47 days).

Notes: Source: MDC Civil Engineering Yield Data, 2002

1.) Excludes reservoir surface area.

2.) (….) – Denotes number of days and average daily flow.

2.0 WATER QUALITY MONITORING PROGRAM

The first systematic water quality investigations of the Quabbin Reservoir watershed occurred in the mid 1930's under the guidance of the Metropolitan District Water Supply Commission. As predecessor to the MDC they established the first records of turbidity, color, dissolved oxygen, pH, alkalinity, hardness, and bacteria. To this day the MDC continues a program that has seen little change over the 64 year period since the original construction of the MDC Quabbin laboratory.

The current sampling program focuses on operational aspects, watershed protection functions including threat identification and enforcement, and compliance monitoring to satisfy state and federal drinking water regulations. Presently, the program is comprised of thirty-six sampling stations located on twenty streams, seven ponds and five reservoir stations in the Quabbin Reservoir and Ware River watersheds. Water samples are regularly analyzed for thirteen physiochemical and biological parameters. In CY 2002, Quabbin laboratory gathered, processed and analyzed 2,975 source water samples. Of the 2,975 samples; 2,073 were collected for microbial analysis and 902 samples were collected for chemical analysis. More than 12,000 individual analyses were performed on these samples and nearly half were physiochemical analyses performed at Quabbin laboratory. The remaining analyses were split between physiochemical measurements taken in the field (3920) and bacterial analyses performed at the Quabbin laboratory (3,496). Only ten additional samples were collected and sent to outside laboratories for specialized analysis.

Table 2 below lists Quabbin laboratory water quality parameters and the methods used in the analysis; generally according to Standard Methods for the Examination of Water and Wastewater, 20th Edition. The laboratory maintains its records on permanent bound books and in digital format (Mircosoft Access database). Quality control records are maintained on permanent bound books.

Table 2. QUABBIN LABORATORY: ANALYTICAL AND FIELD METHODS

PARAMETER	STANDARD METHOD (SM)
Turbidity	SM 2130 B
pH	SM 4500-H Hydrolab Data Sonde 4a, Orion 811 meter
Alkalinity	SM 2320 B (low level)
Chloride	SM 4500-Cl^- C.Mercuric Nitrate Method
Hardness	SM 2340 C
Color	SM 2120 B
Conductivity	HACH DREL/5 meter Hydrolab Data Sonde 4a
Temperature	YSI Model 57 DO Meter Hydrolab Data Sonde 4a
Dissolved Oxygen	YSI Model 57 DO Meter Hydrolab Data Sonde 4a
Iron	HACH DR/3 Spectrophotometer
Total Coliform	SM 9222B
Fecal Coliform	SM 9222
Escherichia coli (E. coli)	EPA Modified mTEC Agar Method

2.1 Measurement Units

Chemical concentrations of constituents in solution or suspension are reported in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit of volume of water (liter). One milligram per liter is equivalent to 1,000 micrograms per liter. Bacteria densities are reported as number of presumptive colony forming units per 100 milliliters of water (CFU/100 mL). The following abbreviations are used in this report:

CFS	Cubic feet per second
CFU	Colony forming unit
CU	Color units
MGD	Million gallons per day
NTU	Nephelometric turbidity units
PPM	Parts per million (1 mg/L = 1 PPM)
THMFP	Trihalomethane formation potential
TKN	Total Kjeldahl nitrogen
µS/cm	Microsiemens per centimeter
µmho/cm	Micromhos per centimeter (1 µmho/cm = 1 µS/cm)

2.2 2002 LABORATORY CHANGES

Three significant changes were made to the Quabbin laboratory monitoring program in 2002. Changes were necessary responses to changes in staffing levels, budgetary constraints and a general shift in laboratory priorities. Each change is highlighted below, followed by a discussion of the change and its impact on the program.

- In August, the laboratory discontinued laboratory analysis of chloride on source water samples. Since 1990, this parameter had been monitored at all routine stations on a quarterly basis. Prior to 1990 analysis was performed biweekly. The purpose of the recent change was to allocate staff time to more important resources and, as a side, to limit the production of nitrous mercuric waste. Chloride has a secondary drinking water standard of 250 mg/L, established to avoid brackish tastes. Salt used for highway de-icing is typically the principal source of surface and groundwater contamination. Other sources include sedimentary rocks and waste discharges from hard water softener units. The highest level recorded in 2002 reached 64.1mg/L inside Mill Brook on July 30.

- The Asnacomet Pond Beach Monitoring Program was modified as the day of sample collection was changed from Saturday to Wednesday. In addition, the biweekly monitoring for both bacteriological and chemical parameters at the beach site (SS#116A) has been discontinued. Since 1990, the 116A site had been monitored biweekly during the summer swimming season. The current monitoring program follows the summer swimming season and entails a weekly collection of three water samples (left, right, and middle) and field measurements of water temperature. Water samples are analyzed at the Quabbin laboratory for *E. Coli* and fecal coliform bacteria.

- David Chandler, long-time environmental analyst retired from service in March 2002. Dave had been the primary chemist for Quabbin laboratory since 1983. With Dave's departure, the laboratory chemistry and field sampling duties formerly performed almost exclusively by Dave were equally distributed among four staff members of the Environmental Quality Section. A schedule was implemented in which each staff person was cross trained and rotated into the laboratory on three month intervals.

No changes were made to the core sampling program in regards to sampling frequency, locations and analytical procedures.

2.3 SOURCE WATER QUALITY MONITORING

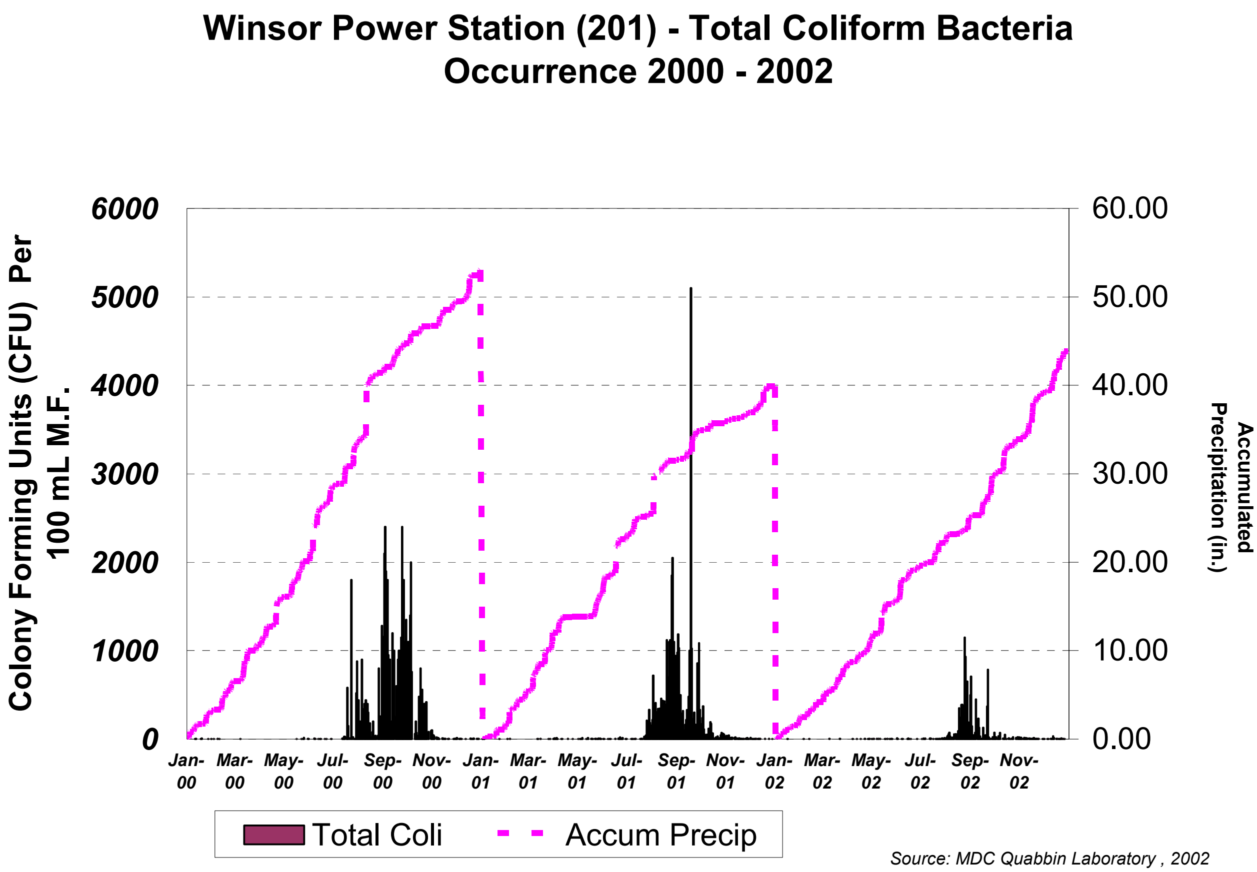
The primary objectives of source water quality monitoring are the protection of public health, compliance with state and federal drinking water regulations and quality control. Table 3 lists the seven source water quality monitoring stations that include sites on the reservoir and at several locations along the two aqueduct systems. Sampling frequency varies and ranges between twice-daily to only once a week, depending on the site.

Primary sites located on the Chicopee Valley Aqueduct are sampled by the MWRA and MDC at a minimum of once daily for both quality assurance and regulatory compliance purposes. Primary sites include: the Winsor Power Station (201), a building tap located at the head of the CVA service line prior to disinfection; the Ludlow Monitoring Station, a chlorinated sample taken by the MWRA from the CVA approximately nine miles downstream of the reservoir; and, Nash Hill a chlorinated sample taken by the MWRA from a tap off of the twenty-five million gallon, covered storage facility. The Chicopee Station located on the CVA service line downstream of Nash Hill is sampled infrequently by the MWRA and only serves as an alternate to the Nash Hill site in the event of a frozen or inaccessible tap. Locations of the source water monitoring sites are depicted in Figure #.

In CY 2002, the MDC laboratory processed 614 finished (after treatment) water samples collected by the MWRA from the CVA aqueduct system. The MDC laboratory tests each MWRA finished water sample for total coliform bacteria with results indicated as presumptive. In the event of a positive result additional tests are conducted to confirm the presence of total coliform bacteria and E. Coli bacteria. The only incident to occur in 2002 involved a sample from the Nash Hill sample site collected on October 4. The sample had tested and was confirmed positive for total coliform bacteria. None of the coliform colonies confirmed as fecal coliform or E. Coli bacteria and repeat samples were negative for coliform bacteria. The incident appeared to be isolated and possibly related to a sampling error.

Site 201 is located at the head of the CVA service line and prior to disinfection. The MDC monitors this water daily for total coliform bacteria. Total coliform bacteria is the umbrella group of bacteria utilized in the water supply field as an indicator of sanitary quality. The total coliform organism in itself is not pathogenic and is native to soil and decaying vegetation, making it ubiquitous in nature. Its utility to the MWRA monitoring program is the quality assurance value derived when results are compared to finished water samples. Total coliform levels at the 201 site have historically been very low, averaging 7 CFU per 100 mL during the 1990-99 period. However, a recent trend of increasingly higher spikes in total coliform bacteria levels beginning during the mid-summer months and lasting until early-fall may be suggesting a watershed phenomena that is still unclear. Researchers from the University of Massachusetts have studied monitoring data and climatological data from the 1995-2000 period to try to explain why recent maximum levels are 20 to 40 fold increases over pre-1999 levels. While researchers have developed possible theories that might explain the apparent rise in total coliform levels, the general consensus is that more data is needed to better understand transport dynamics of total coliform bacteria. One theory that could explain larger than normal coliform bacteria spikes relates in-reservoir levels to larger than normal land-stores of bacteria created by extended periods of direr than normal weather (or, conversely extensive watershed flushing caused by wetter than normal weather) (Lee & Long, 2002). It should be noted that the land-store effect is only one theory under consideration and that it is still in the infancy stage of study. Figure 6 below graphically portrays the pattern of recent total coliform bacteria levels and compares it to accumulated precipitation for the past three years. The plot pf accumulated precipitation graphically suggests that an increase in slope results in higher and more sustained total coliform bacteria spikes. In 2002, the highest concentration reached was 1150 CFU per 100 mL on August 24. The average total coliform concentration during the period of elevated levels was 84 CFU per 100 mL. The spikes in the 2002 levels were generally lower in magnitude and duration than in previous years.

Figure 4



At Site 201, fecal coliform bacteria monitoring is required for compliance with Source Quality Criteria determinations stipulated under the federal SWTR of 1989. Site 201 is monitored at a minimum of once daily and twice daily during active phases of the G*ull Control Program*. Fecal coliform bacteria was absent in 368 of 435 (84.6%) of the samples collected from Site 201. The annual fecal coliform concentration averaged less than 1 colony forming unit (CFU) per 100 milliliters (mL). The highest concentration reached was 21 CFU per 100 mL on December 12 and marked the first time since December 1994 that the source water standard of 20 CFU per 100 mL was exceeded. The exceedance was attributed to the presence of untrained gulls (numbers estimated to vary between 200 and 1000) unfettered by an MDC Gull Control Program that was being scaled back due to budget constraints. The next highest fecal coliform concentration was 7 CFU per 100 mL measured on December 17, at a time when full gull control harassment measures were in-place. The reason behind the difference in total verses fecal coliform bacteria levels is the longer survival time of environmental coliform strains of no sanitary significance that are included under the umbrella of the total coliform group.

Physiochemical parameters are also monitored weekly at Site 201 and these include temperature, dissolved oxygen, turbidity, pH, alkalinity and specific conductance. Color, hardness and iron measurements are performed quarterly. The above parameters may be considered physical parameters and most have established state and federal Secondary Drinking Water Standards. Secondary standards have been established for contaminants not known to cause a health risk but that

USEPA Secondary Drinking Water Standards

- Color: 15 CU
- pH: 6.5-8.5
- Iron: 0.3 mg/L
- Total Dissolved Solids: 500 mg/L
- Hardness: 500 mg/L (World Health Organization)

may affect taste, odor, or aesthetics of the water. Turbidity is one physical parameter that has assumed the added role as a "microbiological parameter". Suspended turbidity has the ability to shelter and protect viruses, pathogens and bacteria from the lethal effects of disinfection. Turbidity is specifically regulated under the SWTR as a treatment technique. Under federal regulations, filtration avoidance criteria is 1 NTU as a monthly average except that levels up to 5 NTU may be allowed in cases where the it can be shown that higher levels did not interfere with disinfection effectiveness and the maintenance of a disinfection residual. The MWRA is responsible for compliance monitoring of this parameter and utilizes a continuous on-line recorder located at the Ware Disinfection facility. High winds from a nor-easter on December 25 caused turbidity levels at the Ware Disinfection facility to exceed the DEP standard. As a result the facility was shut down for approximately 7 hours until winds diminished in strength (MWRA, 2002). In weekly assessment monitoring performed by the MDC the average annual turbidity was characteristically low, measured as 0.4 NTU.

Site 201 is also tested bi-weekly (happening once every two weeks) for the presence of *Giardia* and *Cryptosporidium*. Both *Giardia lamblia* and *Crptosporidium parvum* have been associated with widespread, waterborne outbreaks of gastrointestional disorders such as diarrhea, cramping and nausea. The diseases are more serious (as it may be fatal) to those with immuno-compromised disorders such as AIDS, cancer patients and the very young and old. Sampling requires the collection and filtering of large quantities of water (100 gallons), specialized concentration of oocysts and examination by microscopy. During 2002, twenty-four samples were collected by MDC staff and sent to the Erie County Water Authority of New York for analysis. All 2002 results were below detection limits. Detection limits ranged from 0.26 to 1.32 cysts per 100 liters. Baseline data on the presence of these microorganisms builds on a database that was begun in 1994. Specifics on this sampling program are discussed further in the Special Investigations section of this report.

Samples are collected weekly from the shore at Shaft 12 to characterize the quality of water entering the Quabbin Aqueduct. Source water quality monitoring stipulated under the SWTR is not required at this location because Quabbin Reservoir water "daylights" to Wachusett Reservoir before completing its 65 mile journey to the metropolitan Boston area. The same parameters monitored at Site 201 are monitored at Shaft 12 (Site 206) with the only difference being that coliform bacteria monitoring is conducted on a weekly basis, as opposed to a daily basis. Results highlighted in Table 4 show there to be little variation between the two reservoir source water stations and (with the exception of total coliform bacteria) little fluctuation of parameter levels throughout the year.

Table 3 – 2002 Source Water Compliance and Quality Assurance Sample Stations		
Station	Location	Frequency
Ludlow Monitoring Station (LMS)	Chicopee Valley Aqueduct, Route 21 Ludlow.	Daily – AM collection seven days a week.
Nash Hill	Chicopee Valley Aqueduct, storage facility.	Daily – Constitutes AM collection Monday through Friday or as often as possible.
Chicopee	Chicopee Valley Aqueduct, Chicopee Water Treatment Plant.	Site serves as an alternate to Nash Hill and thus is sampled infrequently.
(201) Winsor Power Station	Building tap located on Chicopee Valley Aqueduct prior to disinfection.	Daily – Constitutes AM collection Monday through Thursday. Sampling is increased with an additional PM sample collected seven days a week during phases of the *Gull Control Program.*
(206) Shaft 12 shoreline	Shoreline beside Shaft 12 intake building	Weekly
(101) Ware River at Shaft 8	Ware River immediately downstream of Shaft 8 intake works building.	
Shaft 11A	Quabbin Aqueduct outlet on Quabbin Reservoir shoreline, east of baffle dams.	Weekly during Ware River diversions.

Physiochemical and bacterial monitoring at the intake works structure in Barre at Shaft 8 is performed biweekly (happening once every two weeks). Like Shaft 12, source water quality sampling at this location is not required under state and federal regulations but is performed for assessment purposes. Diversions from Ware River to Quabbin Reservoir are permitted without DEP approval from October 15 to June 15 but are limited to periods when Ware River flows exceed 85 MGD. Table 5 exhibits the notable improvement in water quality observed during the allowable diversion period. For instance, during the allowable diversion period fecal coliform bacteria levels averaged 9 CFU per 100 mL and turbidity levels equaled or exceeded 1 NTU in 10 of 18 grab samples. In contrast, during the non-diversion period fecal coliform bacteria averaged 63 colonies per 100 mL and turbidity equaled or exceeded 1 NTU in 9 of 9 grab samples. None of the grab samples had turbidity levels above 5 NTU. The Quabbin Aqueduct outfall at Shaft 11A, located on the reservoir shoreline in Hardwick, is sampled infrequently during times of active diversion and only during regularly scheduled, weekly tributary monitoring runs. In 2002, the Shaft 11A site was only sampled on eight occasions. Shaft 11A results are included in the appendix of this report.

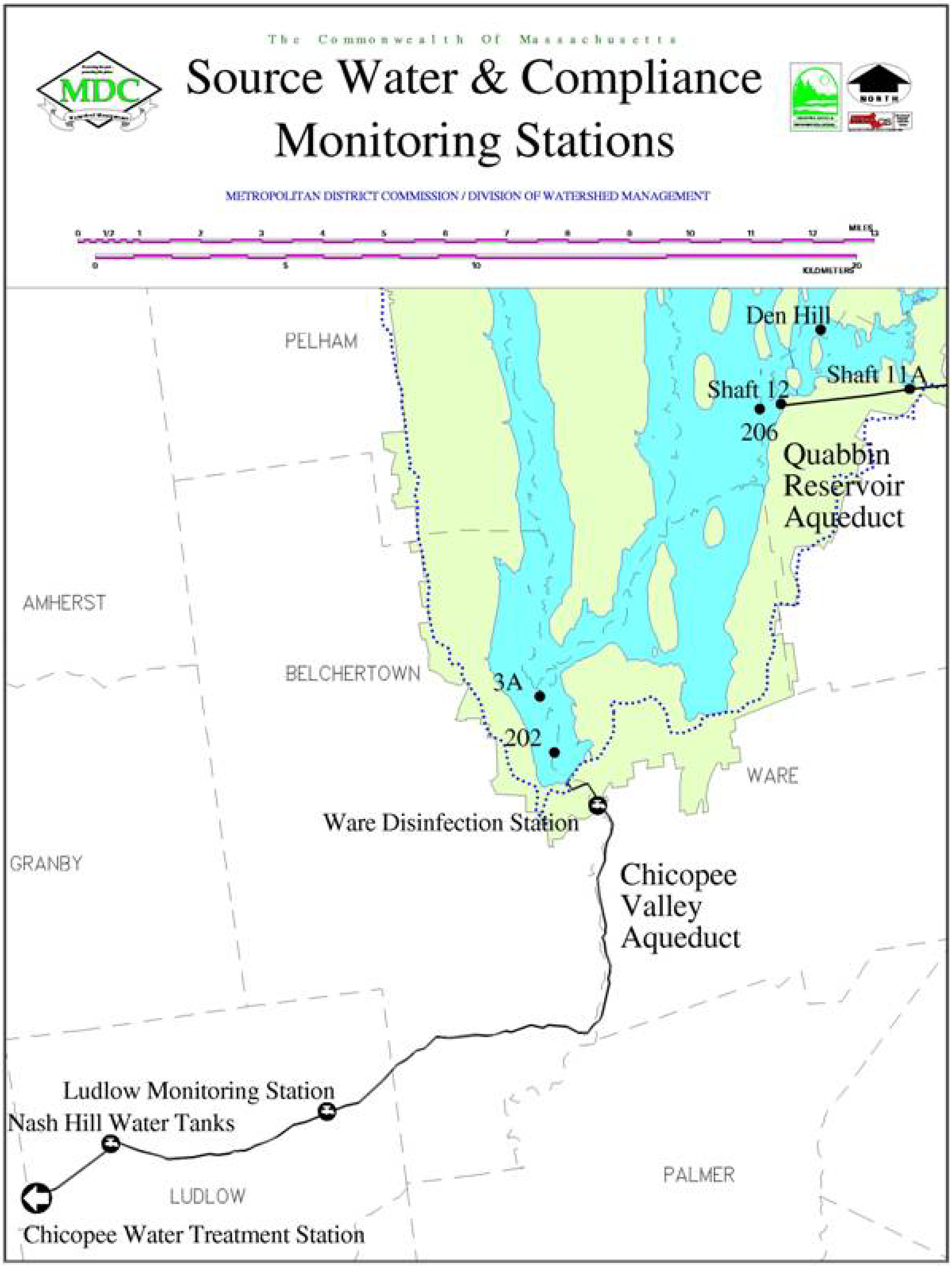

The Commonwealth Of Massachusetts
MDC
Source Water & Compliance Monitoring Stations
METROPOLITAN DISTRICT COMMISSION / DIVISION OF WATERSHED MANAGEMENT
NORTH
MILES
KILOMETERS
PELHAM
Den Hill
Shaft 12
Shaft 11A
206
Quabbin Reservoir Aqueduct
AMHERST
BELCHERTOWN
3A
202
WARE
Ware Disinfection Station
GRANBY
Chicopee Valley Aqueduct
Ludlow Monitoring Station
Nash Hill Water Tanks
LUDLOW
PALMER
Chicopee Water Treatment Station

Figure 5

Table 4 – 2002 Quabbin Reservoir Water Quality Data: MDC Sample Stations 201 & 206

	Parameter	Observed Range of Values					Massachusetts Water Quality Standard
		Min.	Max.	Avg.	Median[1]		
					CY 2002	% Change vs. Historic	
Site 201 Winsor Power Station	***Biological***						
	Total Coliform Bacteria	0	1150	30	1	-100%	No Standard
	Fecal Coliform Bacteria	0	21	<1	0	NC	† mean ≤20
	Physical Characteristics						
	Turbidity (NTU)	0.25	1.5	0.35	0.3	NC	See narrative text.
	Color (units)	5	5	5	5	NC	†† 15
	Dissolved Oxygen (mg/L)	8.2	14.0	11.0	10.9	+0.9%	† min. 6.0 mg/L
	Temperature (°C)	3	21°C	10.7°C	10°C	NC	† max. ≤20°C
	pH (units)	6.43	6.94	6.7	6.6	+1.5%	† 6.5-8.3
	Alkalinity (mg/L as CaCO3)	3.6	5.4	4.3	4.3	+4.9%	See narrative text.
	Hardness (mg/L as $CaCO_3$)	7.3	8.1	7.7	7.75	-17.6%	See narrative text.
Site 206 Shaft 12 Shore	***Biological***						
	Total Coliform Bacteria	0	750	36	3	-50%	No Standard
	Fecal Coliform Bacteria	0	5	<1	0	NC	† mean ≤20
	Physical Characteristics						
	Turbidity (NTU)	0.2	0.8	0.3	0.3	NC	See narrative text.
	Color (units)	5	7	5.4	5	NC	†† 15
	Dissolved Oxygen (mg/L)	7.7	13.7	10.5	10.6	+3.9%	† min. 6.0 mg/L
	Temperature (°C)	1°C	26.5°C	12.2°C	11.2°C	+1.8%	† max. ≤20°C
	pH (units)	6.5	7.1	6.76	6.7	+1.5%	† 6.5-8.3
	Alkalinity (mg/L as CaCO3)	3.0	4.7	4.1	4.2	NC	See narrative text.
	Hardness (mg/L as $CaCO_3$)	5.8	9.3	7.7	7.7	-25.2%	See narrative text.

Notes: [1]Historic median values based on MDC Quabbin Laboratory records from 1990 through 1999. "NC" refers to "No Change".

† *MA Inland Class A Water Standards* – Min. criteria for surface waters to sustain and protect them from the degradation of their designated use(s).

†† *MA Secondary Drinking Water Standards* - These standards and meant only to serve as a guide, the parameters are not known to cause a health risk but may affect the taste, odor and color of water.

1.) Coliform concentration reported as presumptive number of colony forming units per 100 mL.

Table 5 – 2001 Ware River Water Quality Data: Shaft 8							
	Parameter	Observed Range of Values					Massachusetts Water Quality Standard
		Min.	Max.	Avg.	Median[1]		
					CY 2002	% Change vs. Historic	
2002 DATA IN WHOLE	***Biological and Physical Characteristics***						
	Total Coliform Bacteria	84	2300	490	333	+177%	No Standard
	Fecal Coliform Bacteria	0	146	28	14	+40%	† mean ≤20
	Turbidity (NTU)	0.45	4.0	1.6	1.4	+75%	See narrative text.
	Color (units)	47	100	64	55	-15%	†† 15
	Dissolved Oxygen (mg/L)	7.7	15.6	11.2	10.9	+3%	† min. 6.0 mg/L
	Temperature (°C)	0°C	23.4°C	9.7°C	8.5°C	-15%	† max. ≤20°C
	pH (units)	5.8	6.9	6.36	6.3	NC	† 6.5-8.3
	Alkalinity (mg/L as CaCO3)	2.9	9.3	5.8	5.5	+17%	See narrative text.
	Specific Conductance (micromhos per cm)	70	140	99	100	+61%	See narrative text.
DURING ALLOWABLE DIVERSION PERIOD OCT 15 THRU JUN 15	***Biological and Physical Characteristics***						
	Total Coliform Bacteria	84	1200	363	187	+467%	No Standard
	Fecal Coliform Bacteria	0	27	9	6	+100%	† mean ≤20
	Turbidity (NTU)	0.45	2.0	1.1	1.0	+67%	See narrative text.
	Color (units)	47	60	52	50	-9%	†† 15
	Dissolved Oxygen (mg/L)	9.4	15.6	12.6	13.2	+8%	† min. 6.0 mg/L
	Temperature (°C)	0°C	18.5°C	4.9°C	3.0°C	-25%	† max. ≤20°C
	pH (units)	5.8	6.4	6.2	6.25	+1%	† 6.5-8.3
	Alkalinity (mg/L as CaCO3)	2.9	8.3	4.8	4.9	+20%	See narrative text.
	Specific Conductance (micromhos per cm)	70	140	99	95	+58%	See narrative text.

Notes:
† *MA Inland Class A Water Body Standards* - Minimum standard for surface waters to sustain and protect them from the degradation of their designated use(s).
†† *MA Secondary Drinking Water Standards* - These standards are meant only to serve as a guide, the parameters are not known to cause a health risk but may affect the taste, odor and color of water.
1.) Coliform bacteria concentration reported as number of colony forming units (CFU) per 100 mL.
2.) [1]Historic median values based on 1990 thru 1999 MDC Quabbin Laboratory records. "NC" refers to "No Change". Percent rounded to nearest whole number

2.4 TRIBUTARY WATER QUALITY MONITORING

Tributary water quality monitoring is used as a tool of the watershed management program to assist with identifying subbasins that may require special attention or enforcement actions, and to track overall trends in water quality. Tables 7 and 8 list subwatershed characteristics for each of the twelve Quabbin Reservoir and seventeen Ware River watershed monitoring stations that comprise the tributary monitoring network. Locations of water quality monitoring stations are depicted in Figures 6 and 7 with 2002 results for fecal coliform bacteria, dissolved oxygen and pH displayed graphically. Each station is sampled biweekly (happening once every two weeks) with sampling runs alternating between the two watersheds. Samples are collected at the start of each work week regardless of weather conditions thereby providing a good representation of various flow conditions and pollutant loadings. No changes in sampling frequency or locations were made in CY 2002.

Tributary water samples are analyzed at the MDC Quabbin laboratory for total and fecal coliform bacteria, alkalinity, pH, specific conductance and turbidity. Analysis is also performed quarterly for color, hardness and iron. Water samples are collected using grab sampling techniques. Temperature and dissolved oxygen are determined in the field using a YSI Model 57 dissolved oxygen meter. Water quality data for individual sample stations can be found in Appendix A and B of this report. Tables 9 and 10 list on a watershed scale, the parameters monitored with the range of minimum, maximum, average and median concentrations. Provided below is a more detailed description of 2002 results and the monitoring parameters and their significance to tributary water quality. Information in this section was referenced from the Massachusetts Surface Water Quality Standards, Standard Methods for the Examination of Water and Wastewater, 20^{th} Ed., Principles of Water Quality (1984) and USEPA's 1986 Quality Criteria for Water.

Total Coliform Bacteria

Total coliform organisms are the umbrella group of bacteria utilized in the water supply field as an indicator of sanitary quality. The total coliform organism in itself is not pathogenic and is native to soil and decaying vegetation, making it ubiquitous in nature. Others (i.e. Geldreich, 1968) have concluded little sanitary significance of environmental monitoring for these organisms citing the fact that the total coliform group is comprised mainly of the aerogenes group that is of non-fecal origin and ubiquitous in nature. Moreover, there has been much debate as to whether or not total coliform organisms can multiply inside the stream environment (Streeter, 1934), casting further doubt on the qualitative assessment of the numbers. Nevertheless, the continued reliance upon the total coliform group for regulatory compliance in treated ("finished") water shows its utility in assessing the efficiency of water quality treatment operations and distribution system integrity. In-stream density levels of total coliform bacteria ranged from zero to 7,600 CFU per 100 mL across both watersheds. It is important to note that when viewing the 2002 tributary monitoring results as a whole, total coliform concentrations were 21% higher among the characteristically "pristine" Quabbin Reservoir tributaries than those of the Ware River tributaries.

Fecal Coliform Bacteria

Fecal coliform bacteria are used as indicators of possible fecal matter contamination because they are normal inhabitants of the intestinal tract of man and other animals. Bacteria levels can vary greatly depending upon pollutant inputs, stream temperatures, precipitation inputs and stream flows. Geldreich and Kenner (1969) reported bacterial densities (CFU per gram of feces shed) for cows and humans to be in the range of 230,000 to 13,000,000 respectively. The Massachusetts Class A, inland water standard for fecal coliform is an arithmetic mean of less than or equal to 20 CFU/100mL, and, no more than 10% of representative samples shall exceed 100 CFU/100mL. For purposes of this report, tributaries with the highest concentrations of fecal coliform bacteria were determined based on a scoring system that assigned points according to its ranking among six statistical categories. The statistical categories include median, average, geometric mean, standard deviation, percentage greater than 20 colonies per 100mL and percentage greater than 100 colonies per 100mL. Table 6 on the following page summaries the fecal coliform data comparison and lists the ten highest ranking tributaries. In general, fecal coliform bacteria loadings to most tributaries fell within historic ranges reported over the 1990 to 1999 period.

Among the Ware River Tributaries Whitehall Pond (112), Ware River at Barre Falls (105) and Ware River at Shaft 8 (101) ranked as the top three respectively. Among the Quabbin Tributaries the Middle Branch Swift (213), Atherton Brook (211A) and Hop Brook at Gate (212) were ranked as the highest three. Seven among the top ten sites are suspected to be experiencing problems related to beaver activity in close proximity to the sample site. New beaver activity in 2002 was noted at sites 112 (Whitehall), Burnshirt @ Rt 62, Parker Brook, Hop Brook, and the Ware River at Shaft 8.

Storm generated loadings generally produce the highest in-stream concentrations due to the washing effect that can carry pollutants deposited onto the land into the stream environment. In 2002, the "washing" effect became even more pronounced due to some extended periods of drier than normal conditions that preceded storm events captured during routine sample runs. For instance, both Atherton Brook and the West Branch Swift River experienced very high loadings of fecal coliform bacteria (1900 and 1650 CFU/100mL respectively) in a September 16 storm event that dumped 1.5 inches of rain during the period preceding and during sampling. The higher loadings are uncharacteristic to the "pristine" character of the two subwatersheds and are being attributed to the chance capturing of peak storm water loadings that were enhanced by the extended period of dry weather that preceded the sampling event. Storm generated loadings at 2 of the 10 (Ware River at Barre Falls and Parker Brook) highest ranking sites listed in Table 6 had "wet" geometric mean values more than three times higher than annual mean levels. For purposes of this report, conditions were classified as "wet" when rainfall exceeded ½ inch in the 24 hours prior to sampling or if cumulatively rainfall exceeded 1-inch in the three days prior to sample collection. Only on Burnshirt River at Whitehall Pond (112) was the annual geometric mean higher than the "wet". Factors that could help to explain this phenomena or the lack of variation between wet and dry conditions may be the proximity of the fecal coliform source, the origin of the fecal coliform (on the land verses in the water), and the dilution effects of the waterbody. In 2002, beaver had constructed a new dam and lodge across the old mill structure on Whitehall Pond, approximately 200 feet upstream of the routine sample site.

Table 6 - CY 2002 Quabbin Reservoir and Ware River Tributaries
A Weighted Ranking (Top Ten) of Fecal Coliform Bacteria Loading

Tributary	Site #	Drainage Area (sq miles)	Weighted Rank[1]	Median	Average	Std. Dev	Geometric Mean	Wet Geo. Mean	%≥ 20	%≥ 100
Burnshirt River @ Williamsville Pond	***112***	11.4	1	8	35	50.28	17	11.5	33.3%	14.8%
Ware River @ Barre Falls Dam	***105***	22.0	2	28	37	51.2	14	55.9	52.6%	10.5%
Middle Br. of Swift River @ Gate 30	***213***	9.14	3	17	32	37.3	16.7	49.0	50.0%	8.3%
Atherton Brook @ R202	***211A***	1.83	4	7	103	396.4	9.7	15.8	26.1%	8.7%
Hop Brook @ Gate	***212***	4.52	5	13	59	189.7	11.2	19.9	40.0%	8.0%
Ware River @ Shaft 8	***101***	96.5	6	14	28	36.1	15.2	22.1	42.3%	7.7%
East Branch Fever @ West Road	***215***	4.15	7	5	89.5	360.7	11.6	14.4	37.5%	4.2%
West Br. of Swift River @ Rt. 202	***211***	12.4	8	7	81.4	327.8	10.3	15.9	24.0%	8.0%
Parker Brook @ mouth	***102***	4.9	9	9	47.5	147.6	15.4	55.1	30.8%	7.7%
Burnshirt River @ Rt. 62	***103***	18.4	10	12	46.5	154.6	11.1	29.5	38.5%	3.9%

Source: MDC Quabbin Laboratory Records.
[1]The weighted rank is the order (from highest to lowest) of results from a cumulative score assigned to each site based on its ranking amongst six of the seven statistical categories shown above.
Note: Shaded cells denote Quabbin Reservoir watershed tributaries.

Physical and Chemical Characteristics

<u>% Wetlands</u>

Percent wetland cover in the MDC watershed was estimated using land use classification data obtained from the interpretation Spring 1992-93 aerial photography completed as a component of the MDC/MWRA *Landuse Program*. Several researchers that include Surballe (1992) and Lent *et. al*. (1998) have illustrated the significance of these land use types on the effects of overall composition of water quality in the Quabbin Reservoir watershed. Most recently, Garvey et al (2000) alluded to the statistical significance of east versus west gradients observed in increasing tributary concentrations of total organic carbon, UV_{254} absorbance, Trihalomethane formation potential (THMFP), and the nutrient nitrogen and phosphorous. The observed gradient was explained by echoing previous findings relating the significance of wetland composition in stream chemistry.

Turbidity

Turbidity is the relative measure of the amount of light refracting and absorbing particles suspended in the water column. Turbidity is used as an indicator of water aesthetics and as a relative measure of the water's productivity. Excessive turbidity can interfere with treatment efficiency and may be harmful to aquatic species. The Massachusetts drinking water standard is 5 NTU for source water and 1 NTU for finished water. The highest turbidity value measured in 2002 was 8.5 NTU at Mill Brook on August 26. Among Quabbin Reservoir tributaries, the highest turbidity level recorded was in the Boat Cove Brook at 4.5 NTU on June 24. Median values among Quabbin Reservoir and Ware River tributaries were both low at 0.5 and 0.8 NTU. The median values reflect the fact that turbidity spikes are infrequent and isolated to event loadings.

Color

Particulate matter such as decaying organics and certain inorganic materials can impart color to water. In 2002, the highest levels were detected in quarterly sampling during the summer months; a time when plant decomposition rates and stream temperatures are at their highest. Tributaries with the highest measurements included Longmeadow Brook (200 CU) and Natty Pond Brook (200 CU). Among the Quabbin Reservoir tributaries the West Branch Fever Brook had the highest reading at 120 CU. Lent *et al*. (1998) showed that spatial and temporal gradients were related to the amount of total wetland area.

Dissolved Oxygen

Aquatic life depends on oxygen dissolved in water for its survival. Dissolved oxygen levels are depleted through the oxygen requirements of aquatic life, the decomposition of organic matter and the introduction of foreign oxygen-demanding substances (e.g. chemical oxidants). Stream flow, turbulence, depth and other physical characteristics of the stream principally drive reaeration, and, thus dissolved oxygen levels. The Massachusetts Class A, inland water standard is a minimum of 6.0 mg/L (or min. 75% saturation) for cold water fisheries. Higher life forms require a minimum of about 2 mg/L of dissolved oxygen and game fish typically require at least 4 mg/L. Median oxygen levels were lowest in Longmeadow Brook 5.8 mg/L (49% saturation), Natty Pond Brook 7.6 mg/L (61% saturation) and the Middle Branch Swift River 8.2 mg/L (72% saturation).

Temperature

In 2002, stream temperatures ranged from 0 to 26 degrees Celsius among all tributaries combined. The Massachusetts Class A, inland water standard for a cold-water fishery is a maximum of 20°C.

pH

pH (hydrogen ion activity) is the measure of the water's reactive characteristics. A drop in pH by one unit represents a ten-fold increase in acidity. The lower the pH the more likely the water will dissolve metals and other substances. A value of 7 indicates neutral water. In the environment, pH is also an important factor in the solubility of persistent heavy metals such as mercury. At pH levels below 6, soluble methyl mercury remains incorporated in the water system and can be more readily accumulated in the tissue of living organisms. The standard specified for Massachusetts Class A, inland water ranges from 6.5 to 8.3. In 2002, tributary pH levels ranged from 5.1 to 7.4. The lowest pH levels were generally measured in the tributaries to the western arm of Quabbin Reservoir.

Alkalinity

Alkalinity is a relative measure of water's ability to neutralize acidic inputs, and thus is a measure of a waterbodies defense against acidification. The Massachusetts Acid Rain Monitoring (ARM) project utilizes alkalinity readings in April to categorize and rank sensitivity of waters to impacts from acid rain (right). Among the tributaries nearly half (45%) fall under the endangered category and roughly 41% meet the highly sensitive criteria. Gates Brook is the only tributary that falls under the critical category.

ARM Sensitivity Categories
(Water Resources Research Ctr, Univ. of Mass at Amherst)

Category	Alkalinity (mg/L)
Acidified	≤ 0 and pH≤ 5
Critical	0-2 or >0 and pH≤ 5
Endangered	2-5
Highly Sensitive	5-10
Sensitive	10-20
Not sensitive	>20

Specific Conductance

Conductance is principally used as an indicator of the amount of dissolved minerals within the water. Specific electrical conductance is the measure of the ability of water to conduct an electrical current, which is dependent on the concentration and availability of mineral ions. Elevated levels may be indicative of contamination from road salting, septic system effluent, stormwater discharges or agricultural runoff. Soil type will also have an impact on ion leaching which may help to explain variability among "pristine" sources. Specific conductance levels in the tributaries ranged between 25 and 400 μmho/cm.

Iron (Fe)

Iron is a natural element found in rocks, soil and used widely in steel products and in water supply piping. Iron is generally found in natural water bodies at concentrations below 0.5 mg/L. Concentrations greater than 0.1 mg/L can precipitate after exposure to the air, causing staining and objectionable tastes. Iron concentrations in tributaries ranged between 0.02 to 1.6 mg/L.

Hardness

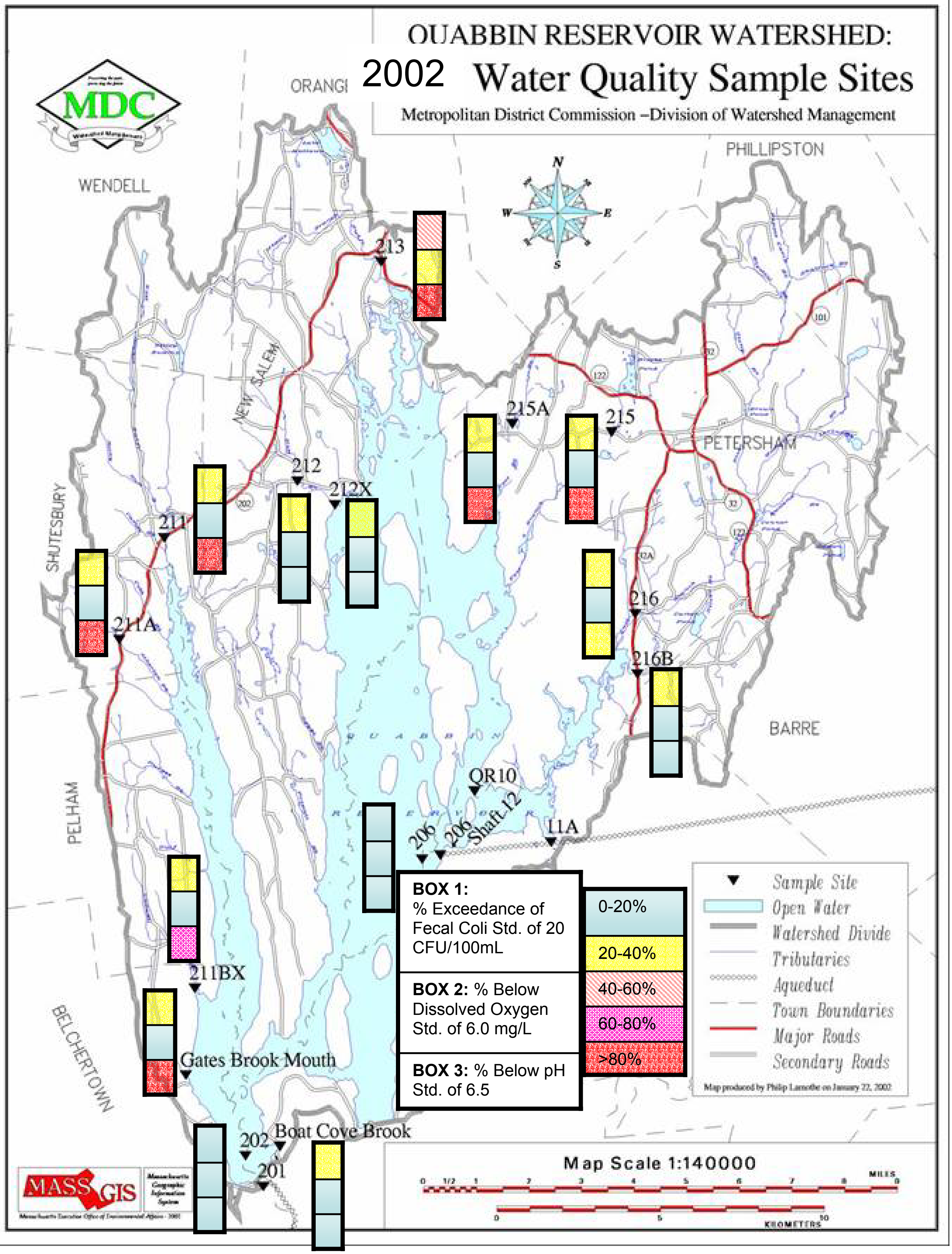
Hardness is principally an indirect measure of the calcium and magnesium ions present in water. In general, water containing less than 50 mg/L as CaCO3 is considered soft and corrosive. In conventional water treatment, hard water has been shown to play a significant role in preventing the leaching of potentially toxic metal ions such as lead, cadmium and zinc from bounded, insoluble complexes. Hardness levels in tributaries ranged between 5.1 to 42.5 mg/L.

Table 7

Quabbin Reservoir Tributaries: 2002 Sampling Sites

Tributary	MDC Sample Site #	*Sample Frequency*[1]	*Basin Characteristics*		
			Drainage Area (sq. miles)[2]	% Wetland Coverage[3]	% MDC Owned Land[4]
East Br. of Swift River @ Rt. 32A	216	BW	30.3	10.4%	1.7%
West Br. of Swift River @ Rt. 202	211	BW	12.4	3.4%	33.0%
Middle Br. of Swift River @ Gate #30	213	BW	9.14	8.1%	22.7%
East Br. of Fever Brook @ West Road	215	BW	4.15	11.5%	12.3%
West Br. of Fever Brook @ Women's Fed.	215A	BW	2.69	8.9%	18.4%
Hop Brook @ mouth	212-X	BW	5.43	2.7%	44.8%
Hop Brook @ Gate 22	212	BW	4.52	2.5%	32.0%
Rand Brook @ Rt. 32A	216B	BW	2.42	9.9%	22.7%
Atherton Brook @Rt. 202	211A	BW	1.83	3.2%	36.0%
Cadwell Creek @ mouth	211BX	BW	2.59	3.3%	98.0%
Gates Brook @ mouth	Gates	BW	0.93	3.2%	100.0%
Boat Cove Brook @ mouth	BC	BW	0.15	<<1%	100.0%

Notes:
[1]BW = biweekly meaning happening once every two weeks. Prior to May 1990 tributaries were monitored on a weekly basis.
[2]Source: Massachusetts Geographic Information System, Executive Office of Environmental Affairs. Latest revision 3/90.
[3]Source: DEP Wetland Conservancy Program (interpreted from 1:12000 Spring 1992-93 photos, latest revision 4/96).
[4]Source: Automated by Massachusetts Geographic Information System & MDC, latest revision 6/97.


QUABBIN RESERVOIR WATERSHED:
2002 Water Quality Sample Sites
Metropolitan District Commission –Division of Watershed Management
MDC
ORANGE
WENDELL
PHILLIPSTON
NEW SALEM
PETERSHAM
SHUTESBURY
PELHAM
BELCHERTOWN
BARRE
213
215A
215
212
212X
211
211A
216
216B
QR10
206
206
Shaft 12
11A
211BX
Gates Brook Mouth
202
Boat Cove Brook
201
BOX 1: % Exceedance of Fecal Coli Std. of 20 CFU/100mL
BOX 2: % Below Dissolved Oxygen Std. of 6.0 mg/L
BOX 3: % Below pH Std. of 6.5
0-20%
20-40%
40-60%
60-80%
>80%
Sample Site
Open Water
Watershed Divide
Tributaries
Aqueduct
Town Boundaries
Major Roads
Secondary Roads
Map produced by Philip Lamothe on January 22, 2002
Map Scale 1:140000
MILES
KILOMETERS
MASS GIS

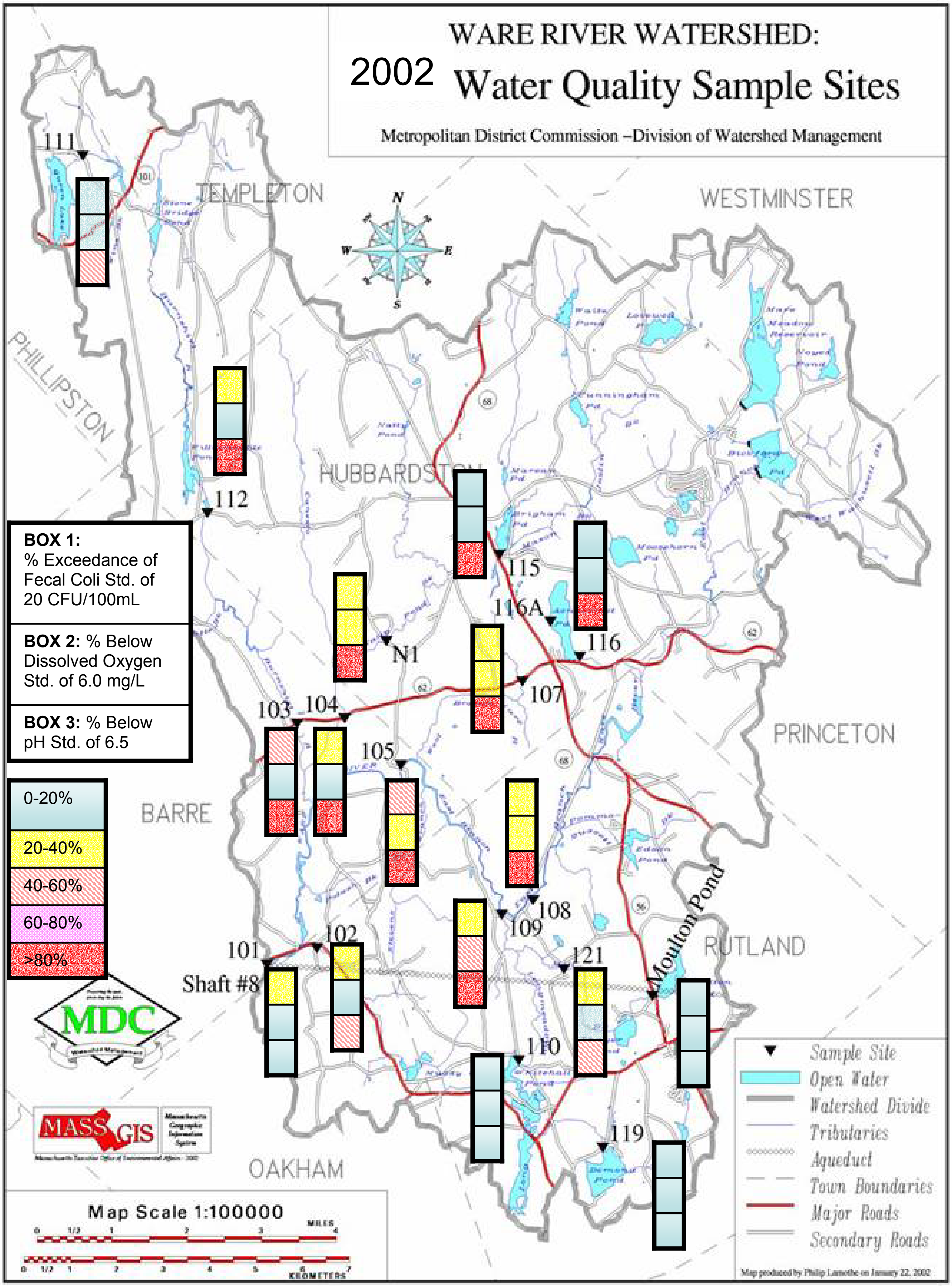

WARE RIVER WATERSHED:
2002 Water Quality Sample Sites
Metropolitan District Commission –Division of Watershed Management
BOX 1: % Exceedance of Fecal Coli Std. of 20 CFU/100mL
BOX 2: % Below Dissolved Oxygen Std. of 6.0 mg/L
BOX 3: % Below pH Std. of 6.5
0-20%
20-40%
40-60%
60-80%
>80%
TEMPLETON
WESTMINSTER
PHILLIPSTON
HUBBARDSTON
BARRE
PRINCETON
RUTLAND
OAKHAM
111
112
115
116A
116
N1
107
103
104
105
108
109
101
102
Shaft #8
121
Moulton Pond
110
119
MDC
MASS GIS
Map Scale 1:100000
MILES
KILOMETERS
Sample Site
Open Water
Watershed Divide
Tributaries
Aqueduct
Town Boundaries
Major Roads
Secondary Roads
Map produced by Philip Lamothe on January 22, 2002

Table 8

Ware River Tributaries: 2002 Sampling Sites

Tributary	MDC Sample Site #	Sample Frequency[1]	Basin Characteristics		
			Drainage Area (sq. miles)[2]	% Wetland Coverage[3]	% MDC Owned Land[4]
Ware River @ Shaft 8 (intake)	101	BW	96.5	13.2%	37.1%
Burnshirt River @ Rt. 62	103	BW	18.4	11.7%	23.5%
Cannesto/Natty @ Rt. 62	104	BW	12.7	8.7%	28.0%
Ware River @ Barre Falls	105	BW	55.1	15.6%	34.5%
Parker Brook @ mouth	102	BW	4.9	9.6%	82.7%
West Branch Ware @ Rt. 62	107	BW	16.6	15.1%	44.9%
East Branch Ware @ New Boston Rd.	108	BW	22.0	16.5%	12.3%
Longmeadow Brook @ mouth	109	BW	12.2	16.5%	47.8%
Long and Whitehall Pond @ outlet	110	BW	5.4	17.8%	37.7%
Queen Lake @ road culvert	111	BW	0.7	36.8%	0%
Burnshirt River @ Williamsville Pond	112	BW	11.4	14.5%	2.5%
Natty Pond Brook @ Hale Road	N1	BW	5.5	14.0%	33.2%
Moulton Pond @ outlet	Moult Pd	BW	1.7	16.4	2.0
Brigham Pond @ outlet	115	BW	11.4	15.4	37.4
Asnacomet Pond @ outlet	116	BW	0.8	29.8	20.9
Demond Pond @ outlet	119	BW	2.3	18.2	14.2
Mill Brook @ Charnock Hill Road	121	BW	3.5	15.5	13.1

Notes:
[1]BW = biweekly meaning happening once every two weeks. Prior to May 1990 tributaries were monitored on a monthly basis.
[2]Source: Massachusetts Geographic Information System, Executive Office of Environmental Affairs. Latest revision 3/90.
[3]Source: DEP Wetland Conservancy Program (interpreted from 1:12000 Spring 1992-93 photos, latest revision 4/96).
[4]Source: Automated by Massachusetts Geographic Information System & MDC, latest revision 6/97.

Table 9 – 2002 Tributary Water Quality Data: Quabbin Reservoir Watershed						
Parameter	Observed Range of Values					Massachusetts Water Quality Standard
	Min.	Max.	Avg.	Median[1]		
				CY 2001	% Change vs. Historic	
Biological						
Total Coliform Bacteria	25	7,600	655	350	+483%	No Standard
Fecal Coliform Bacteria	0	1900	54	8	+14.3%	† mean 20
Physical and Chemical Characteristics						
Turbidity (NTU)	0.1	4.5	0.7	0.5	+25%	See narrative text.
Color (units)	13	120	42	38	+35.7%	††15
Dissolved Oxygen(mg/L)	3.7	22.7	10.9	10.9	+0.9%	†min. 75%
Temperature	0°C	24.3°C	9.5°C	8°C	NC	†max. ≤20°C
pH (units)	5.1	7.4	6.4	6.4	+1.6%	†6.5-8.3
Alkalinity (mg/L as CaCO3)	1.5	27.4	7.2	5.9	+18%	See narrative text.
Hardness (mg/L as CaCO3)	5.1	33.7	14.8	14.4	+26.3%	See narrative text.
Specific Conductance (micromhos per cm)	25	177	86.5	89	+53.4%	See narrative text.
Inorganic Compounds						
Iron (PPM)	0.02	1.10	0.33	0.23	+76.9%	†† 0.3 PPM
Chlorides (PPM)	***DISCONTINUED IN 2002***					†† 250 PPM

Notes:

† *MA Inland Class A Water Body Standards* - Minimum standard for surface waters to sustain and protect them from the degradation of their designated use(s).

†† *MA Secondary Drinking Water Standards* - These standards are meant only to serve as a guide, the parameters are not known to cause a health risk but may affect the taste, odor and color of water.

1.) Coliform bacteria concentration reported as number of colony forming units (CFU) per 100 mL.

2.) [1]Historic median values based on 1990 thru 1999 MDC Quabbin Laboratory records. "NC" refers to "No Change".

3.) PPM - Parts per million, equivalent to one drop in 10 gallons. 1 PPM = 0.9997 mg/L.

Table 10 – 2002 Tributary Water Quality Data: Ware River Watershed

Parameter	Observed Range of Values					Massachusetts Water Quality Standard
	Min.	Max.	Avg.	Median[1]		
				CY 2001	% Change vs. Historic	
Biological						
Total Coliform Bacteria	0	5733	578	290	+480%	No Standard
Fecal Coliform Bacteria	0	800	26	4	+25%	† mean 20
Physical and Chemical Characteristics						
Turbidity (NTU)	0.2	8.5	1.17	0.8	+33.3%	See narrative text.
Color (units)	7	200	64	52	+9.5%	††15
Dissolved Oxygen(mg/L)	0.6	17.6	9.6	9.9	+3.1%	†min. 6.0 mg/L
Temperature	0°C	26°C	9.9°C	8°C	+12.5%	†max. ≤20°C
pH (units)	5.5	7.1	6.4	6.4	+1.6%	†6.5-8.3
Alkalinity (mg/L as CaCO3)	2.1	34.9	7.5	6.5	+18.2%	See narrative text.
Hardness (mg/L as CaCO3)	6.1	42.5	16.9	13.2	+4.8%	See narrative text.
Specific Conductance (micromhos per cm)	30	400	126	85	+46.6%	See narrative text.
Inorganic Compounds						
Iron (PPM)	0.03	1.6	0.54	0.49	+75%	†† 0.3 PPM
Chlorides (PPM)	***DISCONTINUED IN 2002***					†† 250 PPM

Notes:

† *MA Inland Class A Water Body Standards* - Minimum standard for surface waters to sustain and protect them from the degradation of their designated use(s).

†† *MA Secondary Drinking Water Standards* - These standards are meant only to serve as a guide, the parameters are not known to cause a health risk but may affect the taste, odor and color of water.

1.) Coliform bacteria concentration reported as number of colony forming units (CFU) per 100 mL.

2.) [1]Historic median values based on 1990 thru 1999 MDC Quabbin Laboratory records. "NC" refers to "No Change". Percent rounded to nearest whole number.

3.) PPM - Parts per million, equivalent to one drop in 10 gallons. 1 PPM = 0.9997 mg/L.

2.5 Reservoir Monitoring

The reservoir monitoring program builds on a historic data set that is used to track the ecological health of the reservoir and to detect trends that may signal changes to the trophic status of the reservoir. The data has been used to develop specialized models of reservoir dynamics and for the purpose of tracking long-term trends. Water quality data is collected monthly except during periods of adverse weather and ice conditions in the winter. Three sampling stations that were routinely sampled in 2002 are profiled in Table 11 below. Figure 6 may be referenced for the specific locations of each sample site.

Table 11 – 2002 Quabbin Reservoir Water Quality Monitoring Sites

Site	Location	Latitude Longitude	Bottom Depth
Winsor Dam (QR202)	Quabbin Reservoir west arm, off shore of Winsor Dam along former Swift River riverbed.	N 42°17'15" W 72°20'59"	44 meters
Shaft 12 (QR06)	Quabbin Reservoir at site of former Quabbin Lake, off shore of Shaft 12.	N 42°22'11" W 72°16'53"	28 meters
Den Hill (QR10)	Quabbin Reservoir eastern basin, north of Den Hill	N 42°23'23" W 72°15'57"	20 meters

Water samples were collected at depth with a kemmerer bottle and analyzed at Quabbin laboratory for turbidity, color, pH, alkalinity, chloride, hardness and iron. Samples for total and fecal coliform bacteria are taken at the surface, 5 meter depth and at the respective water supply intake depth. Physiochemical samples are taken from mid-epilimnion and mid-hypolimnion during times of thermal stratification, and near the top and bottom during periods of isothermy and mixing. Wind, weather, reservoir conditions and air temperature are recorded on each survey. A standard 20 cm diameter black and white secchi disk is used to measure transparency.

Water column profiles of temperature, pH, dissolved oxygen, and specific conductance are measured "in-situ" using a Hydrolab Data Sonde 4a multiprobe. Readings are taken every meter during times of thermal stratification and mixing, and every three meters during periods of isothermy. Field data is stored digitally in a hand-held Hydrolab Surveyor 4A and transferred to a computer database maintained at Quabbin laboratory.

Table 12 presents an overview of reservoir water quality conditions at three stations routinely monitored in 2002. The complete data for individual stations is included in Appendix A. Provided below is a brief discussion of selected monitoring parameters and their significance to reservoir water quality conditions. In general, water quality results fell within historic ranges, however, dynamic fluctuations were observed in reservoir total coliform bacteria levels.

Table 12. General Water Chemistry. 2002 Quabbin Reservoir Monitoring Stations.

	pH	**Turbidity**	**Color**	**Dissolved Oxygen**	**Secchi Disk Transparency**	**Specific Conductance**
Reservoir Station	Range (units)	Range NTU	Range CU	Range % Saturation	Range (meters)	Range (μmhos/cm)
Winsor Dam (QR202)	5.35-6.76	0.2-0.3	5-10	43.7-104.2	8.1-10.9	40.1-43.3
Shaft 12 (QR206)	5.38-6.75	0.2-0.5	5-10	30.0-100.9	6.6-10.0	40.1-45.9
Den Hill	5.51-6.75	0.3-0.55	10-15	5.2-98.2	3.7-9.4	45.2-58.0

Total Coliform Bacteria

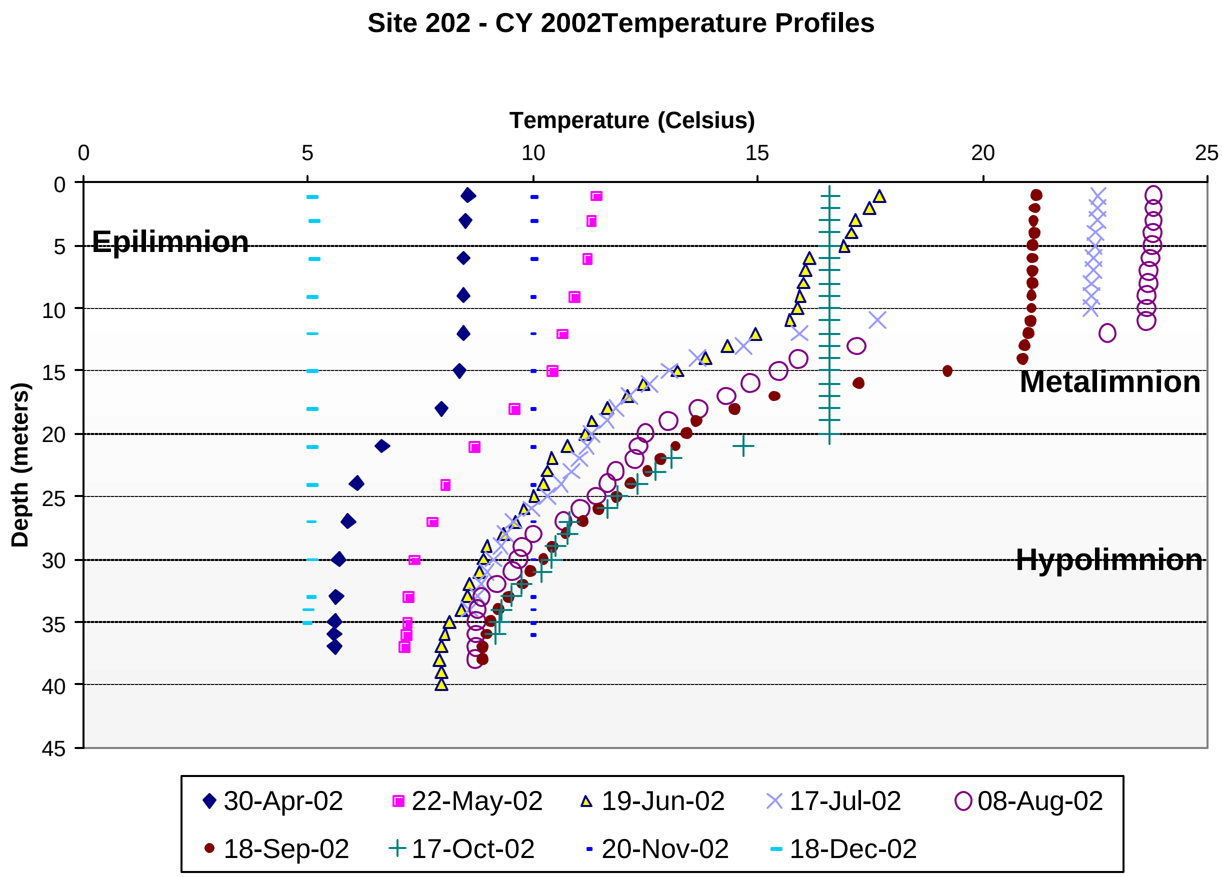
Monthly monitoring of in-reservoir total coliform bacteria levels began on April 30 and ended on December 18. Grab samples were collected from the surface, at the five meter depth, and from the respective water supply intake depth at the two deep basin sites (Shaft 12 and Winsor Dam). On September 18 peak densities were measured at 740 CFU per 100 mL in samples collected at Site 202 from a depth of 18 meters. Insufficient data was collected to accurately characterize in-reservoir total coliform dynamics observed during the mid-summer to mid-fall months.

Fecal Coliform Bacteria

In-reservoir concentrations of fecal coliform bacteria monitored monthly remained very low. Of the 73 samples collected, only 11 (15%) tested positive for fecal coliform bacteria. The maximum concentration was measured at 1 CFU per 100 mL. Seasonal gull populations that roost on the reservoir overnight have been identified as the primary contributor of fecal coliform bacteria contamination to the reservoir. Other sources may include other waterfowl, semi-aquatic wildlife and tributary inputs.

Temperature

The thermal stratification that occurs in the reservoir has a profound impact on many of the parameters monitored across the reservoir profile. The temporal zones that develop within the reservoir during the warmer months of spring and summer, known as the epilimnion, metalimnion and hypolimnion (listed in order from top to bottom), have distinct thermal, water flow and water quality characteristics. Waters of the epilimnion are warm and well mixed by wind driven currents, and, may become susceptible to algal growth due to the availability of sunlight and entrapped nutrients introduced to the partitioned layer of surface water. Within the metalimnion the thermal and water quality transition occurs between the warmer surface waters and colder, deep waters. The much deeper hypolimnic waters remain stagnant, have no circulation, and are susceptible to decaying matter and sediments that settle out from the upper layers of warmer water. Each year the reservoir is completely mixed due the settling of cooler surface waters at the time of springtime ice-out and during the cooling of surface waters in the fall. Profile data collected a Station 202 has been selected to graphically portray the thermal mixing and transition that occurs between fully mixed, isothermal to fully stratified conditions.



Source: 2002 MDC Quabbin Laboratory

Figure 8

Dissolved Oxygen

Dissolved oxygen profile measurements at Station 202 are displayed graphically below in Figure 9. Oxygen is essential to the survival of aquatic life (trout need a minimum of 5.0 mg/L or 44% saturation at 10°C) and available oxygen also plays an important role in preventing the leaching of potentially harmful toxins trapped among the bottom sediments. Dissolved oxygen, or more specifically the loss of oxygen from the hypolimnion, is used is as one index to characterize the trophic state of a lake. Because re-aeration factors such as wind driven turbulence, reservoir currents, and atmospheric diffusion diminish with depth dissolved oxygen concentrations typically decrease with depth. Dissolved oxygen reductions are most pronounced inside the hypolimnic layer of the reservoir where the water remains stagnant and microbial decomposition activity is a large consumer of the available oxygen. Hypolimnic oxygen reserves established in the spring are not replenished until the late fall when cooling surface waters ultimately settle and re-mix the reservoir. In 2002, minimum levels of oxygen reached in the hypolimnion ranged from a low of 5.2% saturation at the Den Hill station to 30.0% saturation at the bottom depths at Shaft 12 (206). Depletion levels were most pronounced in the latter stages of stratification (September and October) and at no time were anaerobic conditions measured.

In the metalimnion and epilimnion oxygen is typically abundant and often super-saturated. In this region the photosynthesis of phytoplankton becomes a factor as it serves as a significant source of oxygen. Another phenomenon that occurs in this region is called the "metalimnic buldge" and is characterized by increasing concentrations of oxygen with depth. The buldge is created when photosynthetically generated oxygen inside the metalimnion becomes entrapped and accumulates inside of the density-restricted zone (depicted in figure below).

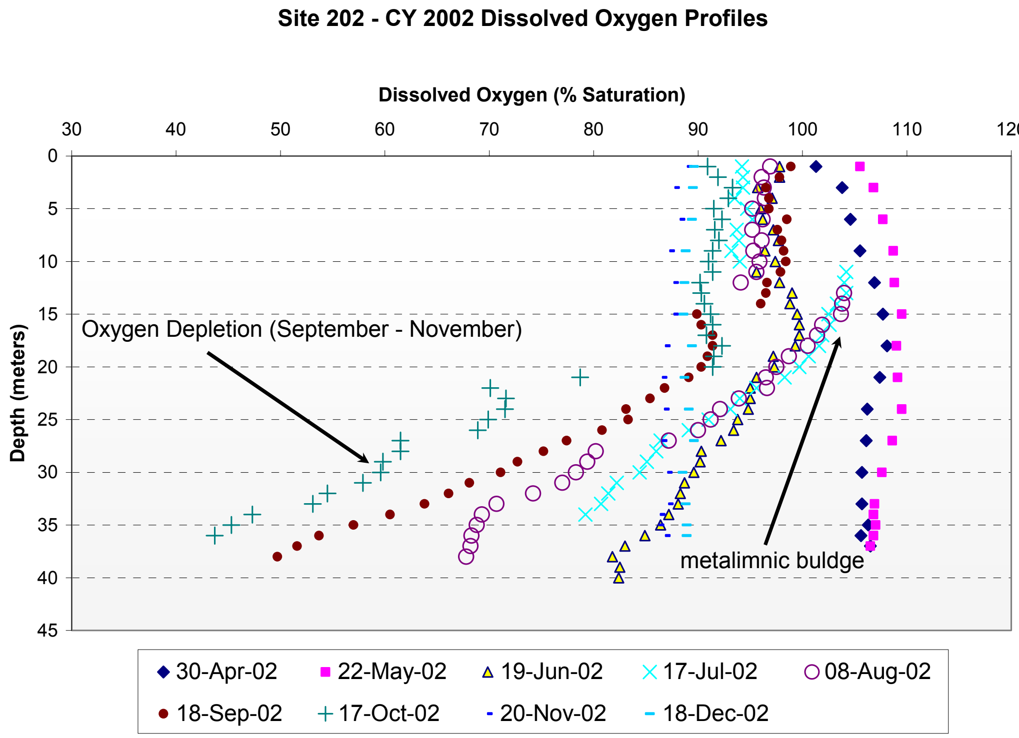


Figure 9

Secchi Disk Transparency

Transparency is a measure of the water's clarity. It is determined as the depth below the surface at which a 20 centimeter black and white disk becomes indistinguishable to the naked eye. Transparency can be greatly influenced by the level of phytoplankton activity but is also sensitive to weather and reservoir conditions at the time of sampling. Quabbin Reservoir's exceptional clarity is evident in the fact that transparency measurements will extend into the metalimnion. In 2002, transparency was measured at a maximum of 10.9 meters at Site 202 on December 18. The Den Hill station is characteristically much lower and reflects the contribution of large, nearby river inputs of the East Branch Swift and Ware River (when diverting). The East Branch Swift River has been estimated to contribute as much as 9% of the annual flow to the reservoir. In 2002, transparency was measured at a minimum of 3.7 meters at Den Hill on October 17. The measurement came at a time when the East Branch Swift River had only just begun to discharge to the reservoir following sixty days of zero flow, and, Ware River diversions had not yet commenced during the allowable diversion period. Monthly transparency measurements are displayed in Figure 10 below.

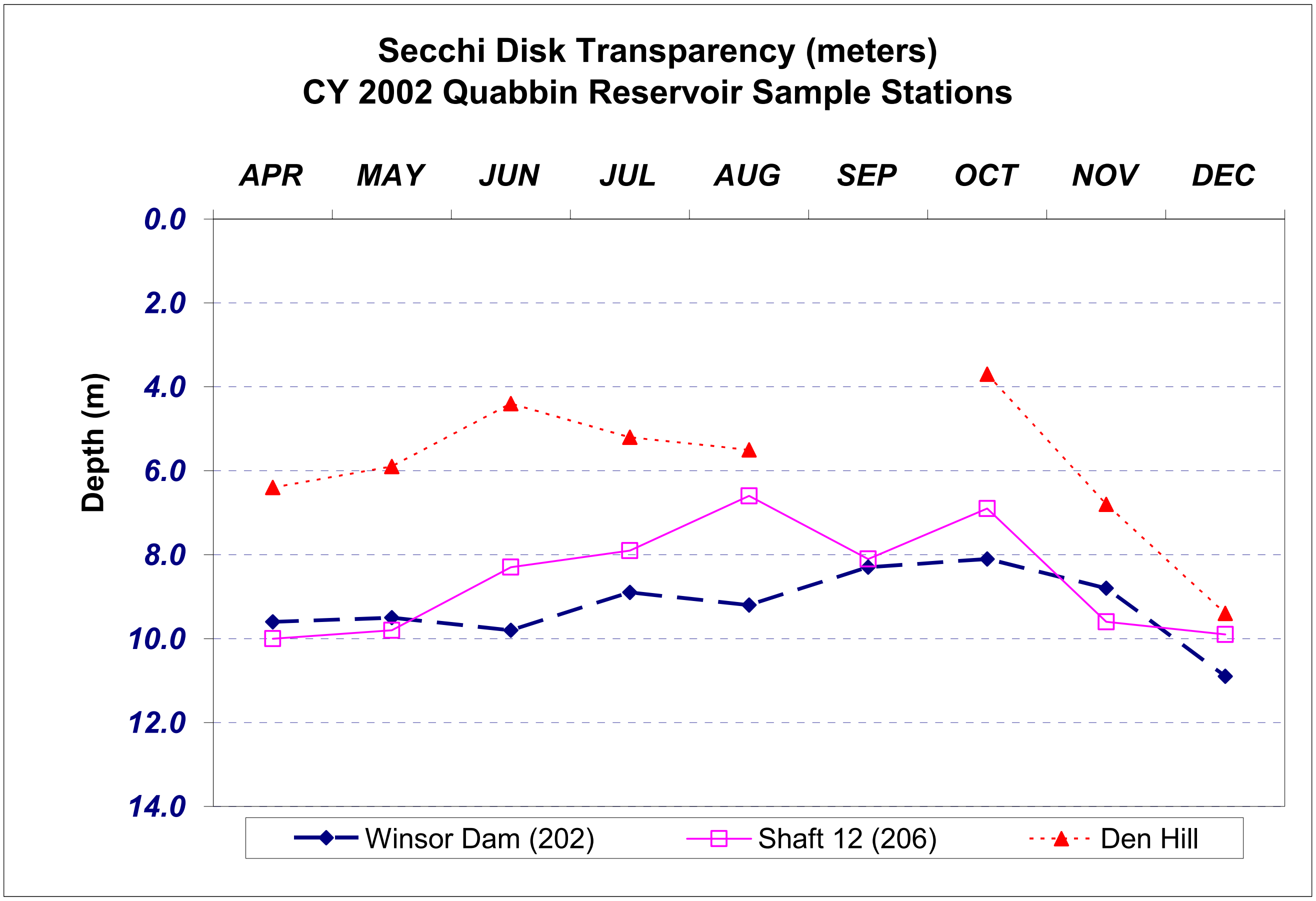


Figure 10

Turbidity and Color

Reservoir turbidity and color levels are very low reflective of the low productivity of the reservoir. In-reservoir turbidity levels monitored in 2002 ranged from 0.2 to 0.55 NTU. From time to time, algae blooms may impart color and suspended organic particulates will elevate levels of turbidity and color. Color values ranged from 5 to 15 color units and where highest at Den Hill where the influence of tributary inputs, higher in organic content, is evident. Color levels did not go above 10 CU at the two, deep reservoir stations at Shaft 12 and Winsor Dam.

pH and Alkalinity

Three processes principally reflected in reservoir pH and alkalinity dynamics are 1) direct acidic inputs (i.e. rainfall), 2) biological respiration and 3) algal photosynthesis. The input of acid in the form of direct precipitation will consume alkalinity available in the water and reduce pH levels. An atmospheric monitoring station has been established on Prescott Peninsula since 1987 to study ambient levels of pH. The monitoring station operated by the University of Massachusetts under the umbrella of the National Atmospheric Deposition Program (NAPD) has been established on Prescott

Peninsula since 1987. NADP data on the level of pH in precipitation has remained stable over the 14 year period ranging between 4.25 and 4.50. Reservoir pH is a water quality issue of concern because levels below 6 increase the solubility of persistent heavy metals such as mercury, allowing the metal to be incorporated into the water system and more readily accumulated in the tissue of living organisms. As evidence to the problem Quabbin Reservoir, like many northeastern lakes, has posted fish consumption advisories that suggest limiting the quantity of fish consumed because of the presence of higher levels of mercury. Alkalinity serves as a water body's principal defense by neutralizing the effects of pH.

Both pH and alkalinity have a long-term record of stability in the Quabbin Reservoir but levels will fluctuate due to reservoir dynamics. Fluctuations may be caused through respiration by organisms as oxygen is consumed and carbon dioxide is released. The result will be an increase in alkalinity due to the input of carbon to the water. Photosynthetic activity in the epilimnion and metalimnion can decrease alkalinity and increase pH due to the consumption of free carbon dioxide and bicarbonate.

Reservoir water is slightly acidic with pH in the epilimnion slightly higher than the bottom waters. Mean (geometric) values in the epilimnion were around pH 6.5 and hypolimnion levels were around pH 5.9 at each of the three stations. Reservoir alkalinity is low and averaged 4.4 mg/L as Ca CO_3 across the three reservoir stations with very little variation observed at depth.

<u>Nutrients and Phytoplankton</u>

Three reservoir stations were monitored quarterly in 2002 for levels of nutrients and phytoplankton. Quarterly sampling was conducted at the onset of thermal stratification (May), in the middle of the stratification period (late July), near the end of the stratification period (October), and during a winter period of isothermy (December). The MWRA Central Laboratory provided analytical support for the analysis of total phosphorous, total kjeldahl nitrogen, nitrate, ammonia, UV_{254} absorbance and silica. Dave Worden, Limnologiost at the MDC Wachusett Section has coordinated the sampling effort and has provided field support and phytoplankton analysis. The 2002 results build on a dataset begun by the MDC in 1998 (see Table 13). Analytical results and a brief summary of the recent data from this ongoing study are summarized below in an excerpt taken from a report produced by Dave Worden, MDC Limnologist.

"*Results of quarterly nutrient sampling in 2002 document concentrations that generally register at the low end of historical ranges. In particular, silica and UV absorbance were measured at concentrations and intensities below the minimum values observed to date. The lowest values of these two parameters were generally observed in October and likely reflect a longer hydraulic residence time and a paucity of runoff resulting from the drought.*

Longer residence time functions to intensify processes in the water column that diminish silica concentrations and UV absorbance. In the case of silica, the process of diatom growth and sedimentation function to remove silica from the water column, much of which is deposited in the sediment as diatom frustules and not recycled. The lower concentrations represent residual silica that remains after depletion by diatom populations acting over a longer period of time.

Similarly, the organic compounds dissolved in the water that absorb UV are subject to microbial degradation and photodegredation and, with prolonged exposure to these processes, the water becomes more transparent to UV. Exacerbating the effects of longer residence time in diminishing silica concentrations and UV absorbance is the dwindling replenishment of these parameters under drought conditions. Due to the paucity of runoff the rate of delivery of silica, dissolved organic compounds and other constituents to the reservoir by tributaries is greatly reduced or ceases entirely.

Despite nutrient concentrations registering at the low end of historical ranges as discussed above, seasonal and vertical patterns in the distribution of nutrients in 2002 quarterly samples were comparable to those documented previously in the 2000 report on Quabbin nutrient and plankton dynamics. These patterns include low epilimnetic and metalimnetic concentrations in summer resulting from phytoplankton uptake and higher concentrations accumulating in the hypolimnion due to microbial decomposition of sedimenting organic matter."

Table 13 - Quabbin Reservoir Nutrient Concentrations:

Comparison of Ranges from 1998-01 Database[(1)] to Results from 2002 Quarterly Sampling [(2)]

Sampling Station [(3)]	Ammonia (NH3; ug/L)		Nitrate (NO3; ug/L)		Silica (SIO2; mg/L)		Total Phosphorus (ug/L)		UV254 (Absorbance/cm)	
	1998-01	Quarterly'02	1998-01	Quarterly'02	1998-01	Quarterly'02	1998-01	Quarterly'02	2000-01	Quarterly'02
WD/202 (E)	<5 - 10	<5 - 11	<5 - 23	<5 - 16	1.14 - 1.73	0.84 - 1.34	<5 - 12	<5 - 8	0.019 - 0.022	0.017 - 0.018
WD/202 (M)	<5 - 29	<5 - 11	<5 - 27	<5 - 16	1.08 - 1.79	0.83 - 1.37	<5 - 13	<5 - 7	0.019 - 0.025	0.017 - 0.020
WD/202 (H)	<5 - 53	11 - 48	<5 - 54	10 - 22	1.18 - 2.58	1.08 - 1.56	<5 - 44	<5 - 6	0.020 - 0.024	0.017 - 0.019
MP/206 (E)	<5 - 8	<5 - 7	<5 - 20	<5 - 15	1.08 - 1.52	0.84 - 1.19	<5 - 12	<5 - 7	0.019 - 0.024	0.017 - 0.019
MP/206 (M)	<5 - 34	<5 - 11	<5 - 44	<5 - 14	0.87 - 1.56	0.84 - 1.22	<5 - 8	<5 - 9	0.020 - 0.027	0.017 - 0.020
MP/206 (H)	<5 - 67	5 - 105	<5 - 29	<5 - 14	1.09 - 1.80	1.02 - 1.92	<5 - 12	<5 - 11	0.020 - 0.024	0.018 - 0.026
Den Hill (E)	<5 - 16	<5 - 12	<5 - 45	<5 - 14	0.98 - 4.64	0.74 - 1.69	<5 - 15	<5 - 8	0.025 - 0.112	0.028 - 0.041
Den Hill (M)	<5 - 16	6 - 25	<5 - 58	<5 - 12	0.86 - 4.37	0.84 - 1.67	<5 - 15	6 - 10	0.027 - 0.090	0.027 - 0.049
Den Hill (H)	<5 - 84	7 - 27	<5 - 74	<5 - 17	1.18 - 4.25	0.83 - 1.96	<5 - 15	6 - 9	0.028 - 0.085	0.028 - 0.054

Notes: (1) 1998-01 database composed of 1998-99 year of monthly sampling and subsequent quarterly sampling conducted through December 2001, except for measurement of UV254 initiated in 2000 quarterly sampling

(2) 2002 quarterly sampling conducted April, July, October, and December

(3) Water column locations are as follow: E = epilimnion/surface, M = metalimnion/middle, H = hypolimnion/bottom

3.0 SPECIAL INVESTIGATIONS

Provided below is a brief overview of specialized studies and investigations that involved Quabbin Reservoir and its contributing tributaries. Laboratory results from MDC DWM field investigations are included in water quality data tables found in the appendices of this report.

Pathogen Monitoring

In coordination with the MWRA, the MDC continued its monitoring program for pathogens at the point of entry to the Chicopee Valley Aqueduct. A total of twenty four samples were collected biweekly from a tap inside the Winsor Power Station (representative of water entering the intake at approximately 70 feet below the reservoir surface). The pathogenic organisms of specific concern are *Cryptosporidium spp*. oocysts and *Giardia spp*. cysts because of their relatively high resistance to disinfectants, prolonged life-cycles and their low doses of infectivity. Sample collection and analysis follows protocols established for the immunoflourescence assay method (IFA Method) under the EPA's 1996 Information Collection Rule. Samples were sent to the Erie County Water Authority of New York for this specialized analysis. MDC staff performs the necessary filtering process during collection and ships the ice-preserved samples within 48 hours of collection. Equipment utilized during collection includes a flowmeter, polypropylene-wound filter cartridge (1 μm), and clear laboratory tubing. A target sample volume of 100 gallons was attained during each sampling event. All 2002 results for pathogens were below detection limits. Detection limits ranged from 0.26 to 1.32 cysts per 100 liters.

Event Based Pathogen Monitoring Research Project – University of Massachusetts

In 2002, the MDC continued a collaborative effort with the University of Massachusetts, Environmental Engineering Program on an AWAARF study that looks to quantify storm water generated, microbiological loadings from various land uses. During 2002, ambient water quality conditions were monitored monthly at each study site and event based sampling was conducted at the two wildlife sites (Griswold and Dickey Brook sites) on March 3, July 28, September 26 and December 14. Also, two agricultural sites, Burrow Brook Woods Road and Burrow Brook Farm that border a cow pasture within the Ware River watershed were established in the late summer and monthly ambient sampling has commenced. In 2002, Quabbin laboratory processed eighty-three samples and analyses was performed on each for total and fecal coliform bacteria. Heterotrophic plate count analysis was also performed on 49 storm water samples collected from three storm events. The MDC will continue to analyze background and storm-event microbiological loadings in 2003

Wildlife Study Site on Dickey Brook

Stream Surveys

DWM staff continued to monitor site-specific water quality impacts related to development pressures, wildlife populations, and construction activities occurring throughout the watersheds. Table 13 summarizes DWM staff investigations, activities and findings.

Table 14. 2002 Special Investigations and Sampling Events

Stream Basin/ Location	**Date(s)**	**Samples Collected?**	**Results**
Middle Branch Swift	April 24	Yes	Follow-up stream survey in response to elevated bacteria levels. Elevated bacteria levels from washed "wrack" sample. Heavy growth on media plates suggested wrack provides ideal environment for bacterial survival.
Middle Branch Swift	May 7	Yes	Follow-up stream survey in response to elevated bacteria levels. Dry-weather samples collected from upstream branches of tributary. Higher bacterial densities from beaver impacted sites. Upper Middle Branch had a low bacteria density.
Cobb Brook, Shutesbury	Aug 6 Oct 31	Yes	Baseline water quality monitoring on headwater reach of tributary to supplement sanitary survey field observations.
Purgee Brook, Pelham	Dec. 23	Yes	Investigative sampling and survey following report of heavy foam in brook.

Reservoir Total Coliform Dynamics

No additional monitoring was conducted in 2002 to study the apparent trend of rising, temporal total coliform bacteria densities. Yuehlin Lee, a University of Massachusetts graduate student under the guidance of Dr. Sharon Long conducted a statistical analysis of water quality and reservoir yield data from the 1995 to 2000 period. Relationships drawn from the statistical analysis were not clear but some interesting theories were developed. One theory previously introduced is the idea of a large land store of total coliform generated by extended periods of drier than normal conditions. In general, the study is in the infancy stage and recommendations were made for more data on wind intensity and direction, vertical total coliform distribution within the reservoir, and additional research on total coliform transport dynamics.

APPENDIX A
WATER QUALITY DATA TABLES

Table A.1 –Tributary Water Quality Data: Quabbin Reservoir Watershed 1998-2001

Parameter	Observed Range of Median Values					Massachusetts Water Quality Standard
	1998	1999	2000	2001	Historic 1990-99	
Biological						
Total Coliform Bacteria	110	170	280	420	55	No Standard
Fecal Coliform Bacteria	6	4	5	6	9	† mean 20
Physical and Chemical Characteristics						
Turbidity (NTU)	0.5	0.4	0.4	0.6	0.4	See narrative text.
Color (units)	28	18	33	28	32	††15
Dissolved Oxygen(mg/L)	10.4	10.6	10.4	10.4	10.1	†min. 6.0 mg/L
Temperature (°C)	7	9	9	9	7.0	†max. ≤20°C
pH (units)	6.3	6.2	6.2	6.4	6.3	†6.5-8.3
Alkalinity (mg/L as CaCO3)	5.3	4.9	5.2	6.8	5.0	See narrative text.
Hardness (mg/L as CaCO3)	12.3	12.9	11.5	12.6	11.40	See narrative text.
Specific Conductance (micromhos per cm)	62	68	63	78	57	See narrative text.
Inorganic Compounds						
Iron (PPM)	0.19	0.13	0.25	0.27	0.18	†† 0.3 PPM
Chlorides (PPM)	12.1	12.2	10.1	13.0	10.35	†† 250 PPM

Notes:

† *MA Inland Class A Water Body Standards* - Minimum standard for surface waters to sustain and protect them from the degradation of their designated use(s).
†† *MA Secondary Drinking Water Standards* - These standards are meant only to serve as a guide, the parameters are not known to cause a health risk but may affect the taste, odor and color of water.
1.) Coliform bacteria concentration reported as number of colony forming units (CFU) per 100 mL.
2.) [1]Historic median values based on 1990 thru 1999 MDC Quabbin Laboratory records. "NC" refers to "No Change". Percent rounded to nearest whole number.

3.) PPM - Parts per million, equivalent to one drop in 10 gallons. 1 PPM = 0.9997 mg/L.

Table A.2 –Tributary Water Quality Data: Ware River Watershed 1998-2001

Parameter	Observed Range of Median Values					Massachusetts Water Quality Standard
	1998	1999	2000	2001	Historic 1990-99	
Biological						
Total Coliform Bacteria	100	120	266	267	50	No Standard
Fecal Coliform Bacteria	3	4	5	5	5	† mean 20
Physical and Chemical Characteristics						
Turbidity (NTU)	0.7	0.7	0.7	0.8	0.6	See narrative text.
Color (units)	47	43	45	58	47	††15
Dissolved Oxygen(mg/L)	9.1	9.7	9.7	8.9	9.6	†min. 6.0 mg/L
Temperature (°C)	10	10	10	12	----	†max. ≤20°C
pH (units)	6.3	6.3	6.3	6.3	6.3	†6.5-8.3
Alkalinity (mg/L as CaCO3)	5.7	5.7	5.7	6.4	5.5	See narrative text.
Hardness (mg/L as CaCO3)	12.4	13.3	11.5	12	12.45	See narrative text.
Specific Conductance (micromhos per cm)	60	72	65	72	58	See narrative text.
Inorganic Compounds						
Iron (PPM)	0.32	0.33	0.52	0.58	0.27	†† 0.3 PPM
Chlorides (PPM)	13.5	43.0	13.5	13.2	11.8	†† 250 PPM

Notes:

† *MA Inland Class A Water Body Standards* - Minimum standard for surface waters to sustain and protect them from the degradation of their designated use(s).
†† *MA Secondary Drinking Water Standards* - These standards are meant only to serve as a guide, the parameters are not known to cause a health risk but may affect the taste, odor and color of water.
1.) Coliform bacteria concentration reported as number of colony forming units (CFU) per 100 mL.
2.) [1]Historic median values based on 1990 thru 1999 MDC Quabbin Laboratory records. "NC" refers to "No Change". Percent rounded to nearest whole number.

3.) PPM - Parts per million, equivalent to one drop in 10 gallons. 1 PPM = 0.9997 mg/L.

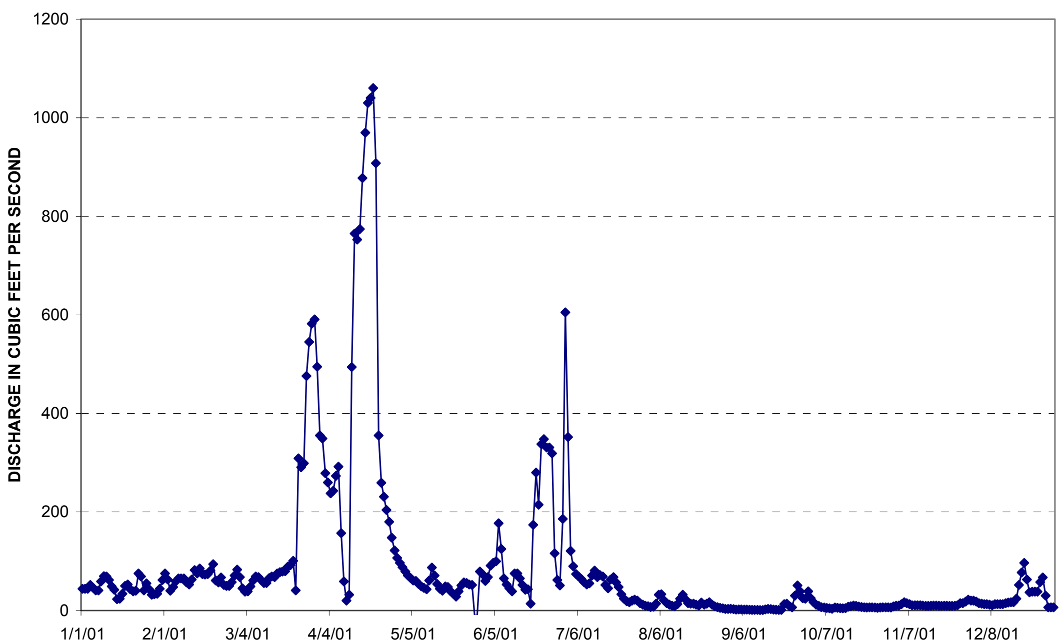
APPENDIX B
WATER QUALITY DATA PLOTS

APPENDIX C
USGS STREAM DISCHARGE DATA

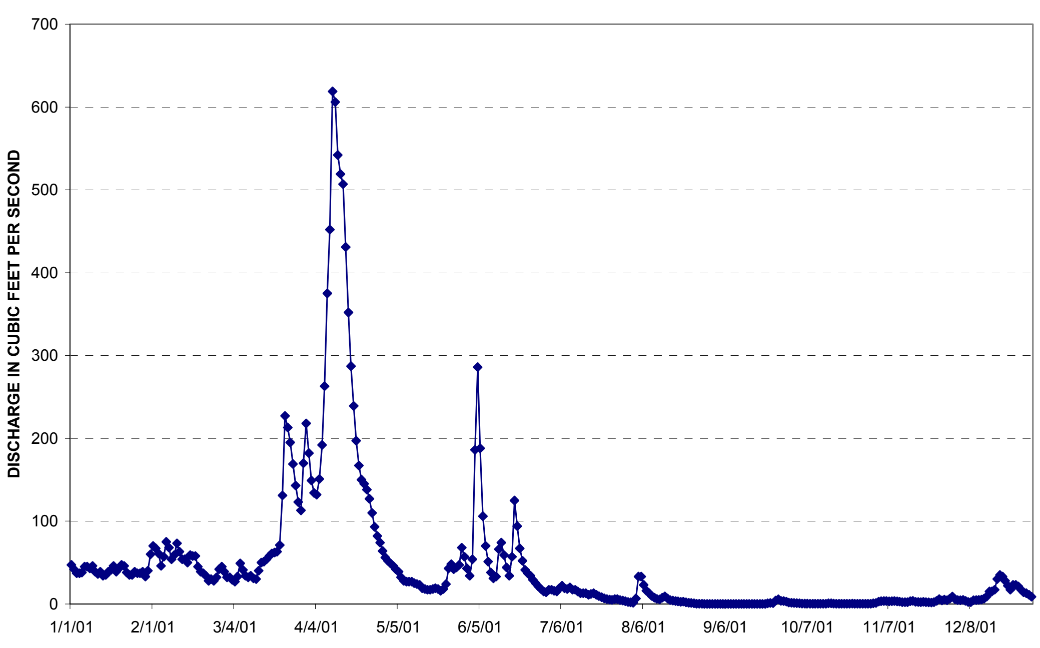
WARE RIVER AT INTAKE WORKS - DISCHARGE, CUBIC FEET PER SECOND (DD 01),
JANUARY 1, 2001 TO DECEMBER 31, 2001
DAILY MEAN VALUES

DATE	Jan 2001	Feb 2001	Mar 2001	Apr 2001	May 2001	Jun 2001	Jul 2001	Aug 2001	Sep 2001	Oct 2001	Nov 2001	Dec 2001
1	44	75	68	349	88	60	605	8.7	3.5	25	8.5	20
2	44	63	45	279	79	68	352	7.4	2.9	17	9.5	18
3	44	40	38	260	71	91	121	7.7	2.2	12	10	15
4	52	48	39	238	66	97	90	14	2.4	9.2	13	14
5	46	59	49	243	61	100	74	32	2.5	6.9	17	13
6	41	65	61	273	60	177	69	33	2.1	5.9	15	13
7	41	65	69	292	54	125	64	21	1.9	5.3	13	12
8	59	65	68	157	49	65	58	15	1.6	4.3	11	11
9	70	57	62	59	46	53	53	12	1.3	3.8	11	13
10	69	53	56	20	43	45	55	9.8	1.3	5.9	11	13
11	62	63	56	32	61	39	71	8.8	1.2	5.6	11	13
12	49	82	66	494	87	75	81	13	0.98	4.8	9.9	13
13	42	75	69	765	71	75	68	24	0.9	4.6	9.4	15
14	23	85	68	753	54	65	72	32	2.4	5	9.4	16
15	24	74	75	774	44	52	69	23	3.4	7.8	9.6	17
16	34	73	78	878	40	42	52	15	2.7	9	10	17
17	50	74	79	970	49	43	45	14	1.9	10	10	24
18	53	81	80	1,030	48	14	63	14	1.6	9.3	9.5	52
19	43	94	89	1,040	39	174	68	12	1.3	8	9.2	77
20	39	61	92	1,060	34	280	57	9.9	1.3	7.2	9.7	97
21	40	57	101	908	28	215	48	16	13	6.6	9.5	63
22	75	67	41	355	39	338	33	12	14	6.1	9.4	37
23	69	52	309	259	51	348	24	14	8.7	6.4	9.1	38
24	41	50	291	231	57	331	19	17	6.4	6.3	9.6	38
25	55	50	299	204	56	331	17	12	30	6.1	11	38
26	43	58	476	180	53	319	20	9	51	5.7	15	58
27	32	71	545	148	52	116	22	7	39	6.1	15	67
28	33	83	582	122	---	62	20	5.7	25	6.4	18	30
29	34		591	107	---	51	15	4.4	24	6.6	22	6.5
30	44		495	97	79	186	12	3.3	39	6.5	20	6.5
31	62		355		74		9.8	3.3		6.2		6.5
MAX	**75**	**94**	**591**	**1,060**	**88**	**348**	**605**	**33**	**51**	**25**	**22**	**97**
MIN	**23**	**40**	**38**	**20**	**28**	**14**	**9.8**	**3.3**	**0.9**	**3.8**	**8.5**	**6.5**
MEAN	47.0	65.7	173.9	419.2	56.3	134.6	78.3	13.9	9.6	7.6	11.8	28.1
STATISTICS OF MONTHLY MEAN DATA FOR WATER YEARS 1928 - 2000												
Wy 28-00 MEAN	**180**	**180**	**327**	**405**	**219**	**139**	**68.4**	**54.2**	**64.7**	**88.5**	**137**	**171**
DEPARTURE FROM NORM	-133.0	-114.3	-153.1	14.2	-162.7	-4.4	9.9	-40.3	-55.1	-80.9	-125.2	-142.9
MIN	**17.2**	**37.5**	**118**	**129**	**73.8**	**18.2**	**9**	**4.94**	**6.12**	**7.86**	**13.9**	**29.1**
MAX	499.0	488.0	1066.0	963.0	438.0	503.0	337.0	319.0	893.0	465.0	445.0	570.0

WARE RIVER AT INTAKE WORKS NEAR BARRE, MA
CALENDAR YEAR 2001



EAST BRANCH SWIFT RIVER NEAR HARDWICK, MA
CALENDAR YEAR 2001



EAST BRANCH SWIFT RIVER NEAR HARDWICK - DISCHARGE, CUBIC FEET PER SECOND (DD 01),
JANUARY 1, 2001 TO DECEMBER 31, 2001
DAILY MEAN VALUES

WEST BRANCH SWIFT RIVER - DISCHARGE, CUBIC FEET PER SECOND (DD 01)
JANUARY 1, 2001 TO DECEMBER 31, 2001

DATE	Jan 2001	Feb 2001	Mar 2001	Apr 2001	May 2001	Jun 2001	Jul 2001	Aug 2001	Sep 2001	Oct 2001	Nov 2001	Dec 2001
1	47	70	32	182	52	34	17	1.9	0.01	1.3	0.68	8.9
2	42	67	32	149	49	54	17	1.5	0	1.2	1.2	5.6
3	37	61	29	134	46	186	16	6.5	0	0.9	2.9	4.8
4	37	46	27	132	42	286	15	33	0	0.7	3.2	4.5
5	38	57	33	151	39	188	19	33	0	0.56	3.4	5
6	45	75	49	192	32	106	22	23	0	0.58	3.6	3.8
7	45	68	41	263	28	70	19	16	0	0.47	3.1	2.4
8	43	54	34	375	27	51	18	13	0	0.24	3.3	2
9	46	59	32	452	27	38	20	9.7	0	0.19	3.4	4.5
10	39	73	34	619	27	31	17	7.5	0	0.2	3	4.6
11	36	63	31	606	25	33	17	6.1	0	0.2	2.8	5
12	39	54	30	542	24	66	15	5.4	0	0.22	2.2	5.1
13	34	54	40	519	23	74	13	7.5	0	0.21	2	6.3
14	35	50	50	507	19	59	13	9.2	0	0.17	2.2	9
15	39	59	51	431	18	44	13	6.6	0	0.63	3.2	15
16	41	58	54	352	17	34	11	4.8	0	0.69	3.7	15
17	46	58	58	287	17	57	12	4.1	0	0.53	2.5	17
18	39	45	61	239	18	125	13	3.6	0	0.35	2.3	30
19	43	39	62	197	19	94	11	3	0	0.25	2.2	35
20	47	37	63	167	18	67	9.3	2.6	0	0.22	2.5	33
21	46	34	71	150	16	52	8.3	2.7	0.1	0.18	2.1	28
22	38	28	131	145	18	41	6.9	1.9	0.74	0.18	1.9	22
23	35	30	227	138	24	37	5.9	1.3	1.1	0.19	1.7	17
24	35	28	213	127	43	34	5.2	1.1	0.89	0.39	2.1	23
25	39	32	195	110	48	29	5	0.59	4.1	0.3	3.8	23
26	37	42	169	93	42	25	5.9	0.33	5.7	0.23	5.8	21
27	37	45	143	82	44	21	5.9	0.21	3.8	0.22	4.3	17
28	39	39	123	74	47	18	4.7	0.18	3.4	0.2	5.1	14
29	33		113	64	68	15	3.9	0.11	2.7	0.17	4.5	13
30	40		170	56	57	14	3.2	0.02	1.6	0.29	6.4	11
31	60		218		43		2.4	0		0.28		8.7
MAX	**60**	**75**	**227**	**619**	**68**	**286**	**22**	**33**	**5.7**	**1.3**	**6.4**	**35**
MIN	**33**	**28**	**27**	**56**	**16**	**14**	**2.4**	**0**	**0**	**0.17**	**0.68**	**2**
MEAN	40.5	50.9	84.4	251.2	32.8	66.1	11.8	6.7	0.8	0.4	3.0	13.4
STATISTICS OF MONTHLY MEAN DATA FOR WATER YEARS 1937 - 2000												
WY 37-00 MEAN	**81.7**	**81.7**	**136**	**160**	**91.9**	**59.4**	**29.1**	**23.2**	**26.4**	**39.1**	**63.4**	**76.6**
DEPARTURE FROM NORM	-41.2	-30.8	-51.6	91.2	-59.1	6.7	-17.3	-16.5	-25.6	-38.7	-60.4	-63.2
MIN	**5.3**	**18.5**	**48.2**	**34.8**	**30.5**	**6.87**	**3.23**	**0**	**0**	**2.55**	**6.93**	**19.9**
MAX	**240**	**207**	**266**	**420**	**189**	**175**	**179**	**127**	**390**	**155**	**177**	**264**

DAILY MEAN VALUES

DATE	Jan 2001	Feb 2001	Mar 2001	Apr 2001	May 2001	Jun 2001	Jul 2001	Aug 2001	Sep 2001	Oct 2001	Nov 2001	Dec 2001
1	15	32	67	36	25	13	13	3.6	1.9	3.2	8.5	5.3
2	16	28	32	32	24	31	12	3.6	1.7	3	9.5	4.6
3	15	30	31	31	22	120	9.9	5.9	1.7	3	10	3.7
4	14	61	30	34	21	57	9.3	6.7	2.3	3.2	13	3.5
5	13	52	44	41	19	34	14	5	2.3	3.2	17	3.3
6	13	109	109	53	18	24	16	4.4	1.9	3.7	15	3.2
7	12	47	59	71	17	19	13	3.8	1.9	3.7	13	3.0
8	12	27	39	110	16	16	11	3.5	1.8	3.3	11	2.8
9	13	28	37	132	15	14	12	3.3	1.7	3.2	11	3.3
10	15	40	39	193	15	12	10	3.2	2	3.4	11	3.1
11	16	101	39	164	14	14	10	2.9	3.4	3.4	11	3.2
12	12	98	40	167	13	33	9.3	2.7	2.7	3.8	9.9	3.3
13	22	32	46	166	12	23	8.5	3.2	2.3	3.7	9.4	4.0
14	12	30	53	171	11	17	8.2	4.9	3.4	3.8	9.4	6.1
15	13	40	31	146	11	14	8.3	5.3	3.3	6.9	9.6	13.2
16	14	36	17	125	11	12	7.4	4.1	2.6	5.9	10	9.2
17	16	40	18	108	11	22	8.4	3.6	2.3	5.2	10	7.3
18	17	81	19	91	11	24	8.2	3.4	2.1	4.1	9.5	13.1
19	17	73	18	78	11	16	7	3.2	2	3.1	9.2	12.2
20	18	31	20	70	10	13	6.4	3.1	2	3.1	9.7	9.2
21	28	34	23	72	9.1	11	6	3	17	2.9	9.5	7.7
22	52	71	72	75	11	10	5.5	2.8	9	2.8	9.4	6.3
23	23	30	101	70	15	21	5.1	2.6	5.6	2.6	9.1	5.3
24	18	29	76	57	21	44	4.8	2.5	4.2	2.9	9.6	9.0
25	18	33	56	46	29	26	4.5	2.2	6.7	2.8	3.2	8.8
26	18	45	43	38	23	18	6.5	2.1	7.2	2.5	4.6	7.0
27	17	41	36	33	30	14	6.1	2.1	5.1	2.3	4.2	5.7
28	17	43	32	30	25	11	4.7	2.1	4.1	2.3	3.8	5.6
29	29		30	28	25	9.9	4.4	2	3.7	2.2	3.9	4.8
30	20		37	26	19	9.6	4.1	1.9	3.3	2.2	4.4	4.0
31	31		41		15		3.9	2		2.1		3.8
MAX	**52**	**109**	**109**	**193**	**30**	**120**	**16**	**6.7**	**17**	**6.9**	**17**	**13.2**
MIN	**12**	**27**	**17**	**26**	**9.1**	**9.6**	**3.9**	**1.9**	**1.7**	**2.1**	**3.2**	**2.8**
MEAN	18.3	47.9	43.1	83.1	17.1	23.4	8.3	3.4	3.7	3.3	9.3	5.9
STATISTICS OF MONTHLY MEAN DATA FOR WATER YEARS 1928 - 2000												
wy 28-00 MEAN	**30.7**	**35.7**	**44.7**	**38.9**	**31.3**	**25.7**	**10.6**	**6.98**	**10.6**	**14.3**	**21.6**	**28.6**
DEPART-URE FROM NORM	-12.4	12.2	-1.6	44.2	-14.2	-2.3	-2.3	-3.6	-6.9	-11.0	-12.3	-22.7
MIN	**11.1**	**13.6**	**30.5**	**15.3**	**10.5**	**3.73**	**1.98**	**2.03**	**1.02**	**2.58**	**6.98**	**7.19**
MAX	51.0	70.6	60.1	83.0	78.1	52.8	24.3	29.3	52.9	29.5	39.2	75.3

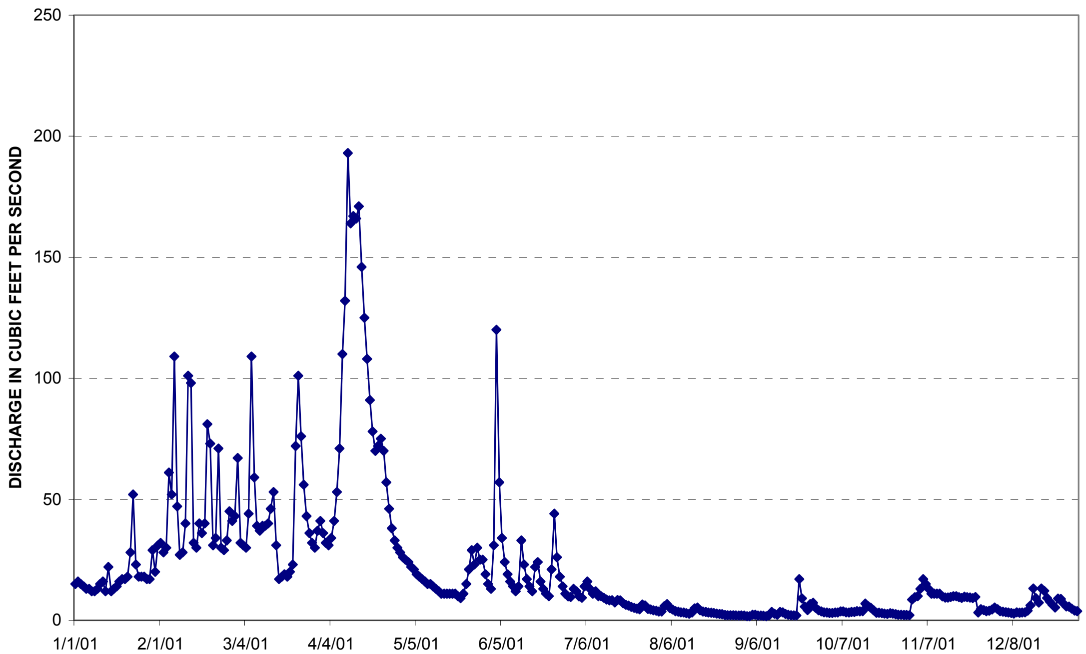
SWIFT RIVER AT WEST WARE - DISCHARGE, CUBIC FEET PER SECOND (DD 01)

JANUARY 1, 2001 TO DECEMBER 31, 2001

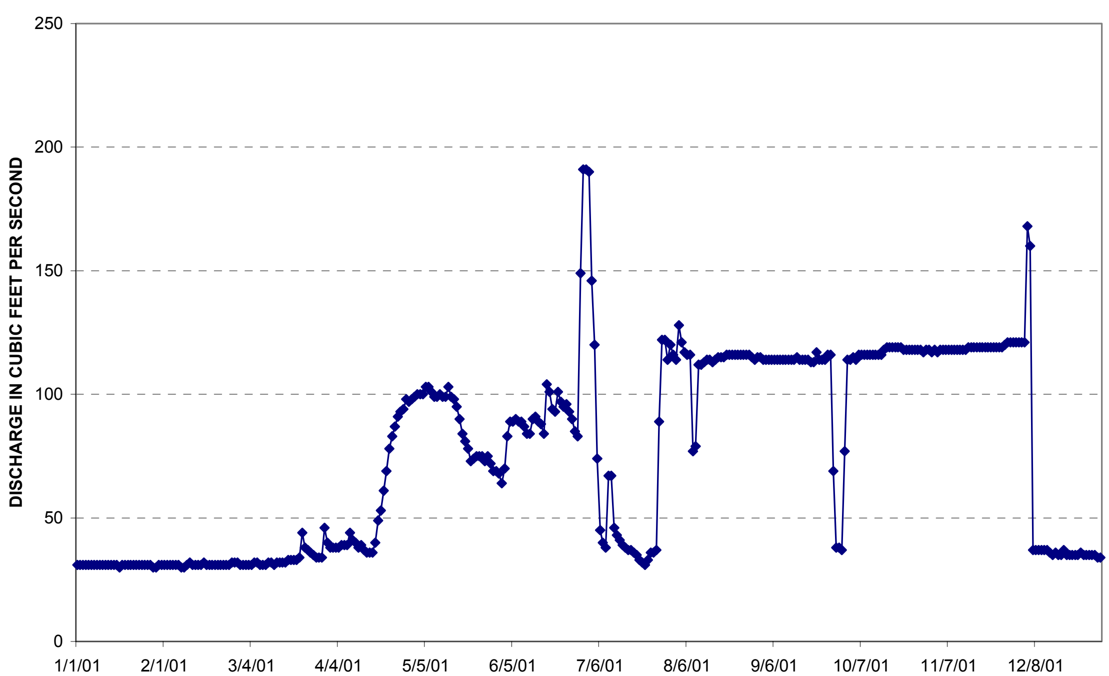
DAILY MEAN VALUES

DATE	Jan 2001	Feb 2001	Mar 2001	Apr 2001	May 2001	Jun 2001	Jul 2001	Aug 2001	Sep 2001	Oct 2001	Nov 2001	Dec 2001
1	31	31	31	38	99	64	191	116	115	77	117	121
2	31	31	31	38	100	70	190	114	114	114	118	121
3	31	31	31	38	100	83	146	128	114	114	117	121
4	31	31	31	38	100	89	120	121	114	115	118	121
5	31	31	32	39	103	89	74	117	114	114	118	168
6	31	31	32	39	103	90	45	116	114	116	118	160
7	31	30	31	39	101	89	40	116	114	116	118	37
8	31	30	31	44	99	89	38	77	114	116	118	37
9	31	31	31	41	99	87	67	79	114	116	118	37
10	31	32	32	40	100	84	67	112	114	116	118	37
11	31	31	32	38	99	84	46	112	114	116	118	37
12	31	31	31	39	99	90	43	113	114	116	118	37
13	31	31	32	37	103	91	41	114	114	116	118	36
14	31	31	32	36	99	89	39	114	115	116	119	35
15	31	32	32	36	98	88	38	113	114	118	119	36
16	30	31	32	36	95	84	37	114	114	119	119	35
17	31	31	33	40	90	104	37	115	114	119	119	35
18	31	31	33	49	84	101	36	115	114	119	119	37
19	31	31	33	53	81	94	35	115	113	119	119	35
20	31	31	33	61	78	93	33	116	113	119	119	35
21	31	31	34	69	73	101	32	116	117	119	119	35
22	31	31	44	78	74	97	31	116	114	118	119	35
23	31	31	38	83	75	95	33	116	114	118	119	35
24	31	31	37	87	75	96	36	116	114	118	119	36
25	31	32	36	91	75	93	36	116	116	118	119	35
26	31	32	35	93	73	90	37	116	116	118	119	35
27	31	32	34	94	75	85	89	116	69	118	120	35
28	30	31	34	98	72	83	122	116	38	118	121	35
29	30		34	97	69	149	122	115	38	117	121	35
30	31		46	98	69	191	114	114	37	118	121	34
31	31		40		68		120	115		118		34
MAX	**31**	**32**	**46**	**98**	**103**	**191**	**191**	**128**	**117**	**119**	**121**	**168**
MIN	**30**	**30**	**31**	**36**	**68**	**64**	**31**	**77**	**37**	**77**	**117**	**34**
MEAN	30.9	31.1	33.8	56.9	88.0	94.4	68.9	113.2	105.1	115.8	118.7	54.9
STATISTICS OF MONTHLY MEAN DATA FOR WATER YEARS 1928 - 2000												
wy 28-00 MEAN	**73.1**	**78.7**	**84.8**	**172**	**165**	**127**	**76.8**	**78.5**	**79.1**	**71.7**	**77.2**	**73.5**
DEPARTURE FROM NORM	-42.2	-47.6	-51.0	-115.1	-77.0	-32.6	-7.9	34.7	26.0	44.1	41.5	-18.6
MIN	**27.5**	**27.6**	**27.7**	**26.2**	**27.4**	**28.6**	**31.2**	**30.7**	**30.3**	**30.3**	**31.3**	**28**
MAX	572.0	467.0	511.0	1099.0	775.0	1192.0	301.0	149.0	139.0	222.0	858.0	656.0

WEST BRANCH SWIFT RIVER NEAR SHUTESBURY
CALENDAR YEAR 2001



SWIFT RIVER AT WEST WARE
CALENDAR YEAR 2001



References:

American Public Health Association, 1998. Standard Methods for the Examination of Water and Wastewater - 20th Edition. Washington D.C..

Geldreich, E.E., 1968. “Fecal Coliform Concepts in Stream Pollution.” Proceedings Symposium on Fecal Coliform Bacteria in Water and Wastewater, Bureau of Sanitary Engineering, State Dept. of Public Health, Berkeley, California.

Jakubowski, J. et al, September 1996. “Environmental Methods for Cryptosporidium”. Journal American Water Works Association.

Long, S.C., May 1997. Development of Methods to Differentiate Microorganisms in MDC Reservoir Watersheds. Dept. of Civil and Environmental Engineering, University of Massachusetts, Amherst.

MA Executive Office of Environmental Affairs, 1999. MA Geographical Information System.

Metropolitan District Commission, 2001. Meteorological Records. MDC unpublished reports.

Streeter, H.W., 1934. “Formulation of Bacterial Changes Occurring in Polluted Water.” *Sewage Works Journal*, Vol. 6, No. 2.

Tobiason J.E., Ahlfeld D.P., Edzwald J.K., Reckhow D.A., Long S.C., April 1999. Water Quality in MDC Reservoirs. Unpublished research proposal to the Metropolitan District Commission prepared by the Department of Civil and Environmental Engineering, University of Massachusetts at Amherst.

Tobiason J.E., Male J.W., Reckhow D.A., September 1996. Contaminant Transport Modeling and the Impact of Watershed Management Activities on Water Quality in Quabbin Reservoir. Environmental Engineering Program, University of Massachusetts at Amherst.

U.S. EPA, 1986. Water Quality Criteria for Water

Waite, T.D. 1984. Principles of Water Quality. Academic Press, Florida.

Wolfram, Evelyn. May 1996. Determination of the Decay Rate For Indicator Bacteria Introduced by Sea Gulls to an Oligotrophic Drinking Water Reservoir. Department of Civil and Environmental Engineering, University of Massachusetts at Amherst.

Worden, David. 2000. Nutrient and Plankton Dynamics in Quabbin Reservoir: Results of the MDC/DWM’s 1998-99 Sampling Program. Metropolitan District Commission, Division of Watershed Management.